TI-1790 A

WADC TECHNICAL REPORT 54-16

AD041362

DETERMINATION OF LEAKAGE VALUES OF SEALS

EARL A. MEYER
ROBERT J. ROTH
W. EUGENE SINNER
DALE HOLINBECK

BJORKSTEN RESEARCH LABORATORIES, INC.

NOVEMBER 1953

WRIGHT AIR DEVELOPMENT CENTER

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

WADC TECHNICAL REPORT 54-16

DETERMINATION OF LEAKAGE VALUES OF SEALS

Earl A. Meyer
Robert J. Roth
W. Eugene Sinner
Dale Holinbeck

Bjorksten Research Laboratories, Inc.

November 1953

Electronic Components Laboratory
Contract No. AF33(038)-15981
RDO No. 112-141

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

Carpenter Litho & Prtg. Co., Springfield,O.
200 - 13 September 1954

FOREWORD

This report, prepared by Bjorksten Research Laboratories, Inc., describes the work performed under Contract No. AF33(038)-15981 and Supplemental Agreement No. S3 (52-380) to Contract No. AF 33(038)-15981. The contract was administered under the direction of the Electronic Components Laboratory, Directorate of Research, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. Mr. David Bedwell was the Electronic Components Laboratory project engineer in charge of the work which was accomplished under RDO No. 112-141, MINIATURIZATION TECHNIQUES FOR AIRBORNE ELECTRONIC EQUIPMENT. Mr. Earl A. Meyer was the engineer in charge of the work for Bjorksten Research Laboratories, Inc.

Research was started on 25 October 1950 and completed 25 October 1953. The manuscript of the report was completed 30 November 1953.

The courtesies of the Development Divison, U.S. Naval Ordnance Plant, Indianapolis, Indiana, the Kearfott Company, and the Marion Instrument Company, in discussing hermetic sealing techniques and measurements, are gratefully acknowledged.

ABSTRACT

The rate of air leakage through various seals in aluminum, brass, and steel specimens was determined quantitatively with one side of the seal evacuated and the other side at one atmosphere. Fusion, adhesive, gasket and lapped type seals on 449 specimens were tested. Leakage rate measurements were made in both directions through the seals before and after various environmental tests of pressure, humidity, vibration and temperature cycling.

The various types of seals were evaluated on the basis of their leakage both before and after specified environmental exposures.

For these measurements two leakage-rate meters were designed and constructed to evaluate leakage rates of 1 to 3,000,000 standard cc. of air/year. Both meters are fully described and drawings for their construction are included. An RCA-1945 Hydrogen Sensitive Ion Gauge was used to measure the smaller leakage rates; and the rate of movement of a water plug in a calibrated capillary was used for the larger leaks.

The non-destructive testing of electronic components on the production line prior to a simple sealing procedure is described and a number of components supplied by WADC were tested.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER:

RICHARD S. CARTER
Colonel, USAF
Chief, Electronic Components Laboratory
Directorate of Research

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

LIST OF ILLUSTRATIONS

INTRODUCTION

A. General

As aircraft operational speeds and altitudes have increased, the electronic components in these ships have been subjected to marked changes in environment. It is obvious that the effects of changing pressure, humidity, temperature and vibration can greatly affect the efficiency of operation of these electronic components. Consequently, a controllable environment, housing these electronic parts and independent as much as possible of exterior conditions, is highly desirable. By the airtight sealing of these containers, control of both humidity and pressure should be possible. Such seals must, in addition to being airtight, withstand changes in temperature and vibration as well. In some cases, a positive seal might be required to seal a gas in a component to prevent an electrical breakdown or to give maximum life to the enclosed equipment.

Not all seals are airtight. From a design standpoint, quantitative data is required to furnish the exact leakage rate of particular types of seals under controlled changes in environment. A Leakage Rate Meter was designed and constructed to supply the required leakage rate data. A total of 449 test specimens representative of the various classes of seals was fabricated for specified environmental exposure and leakage rate evaluation before and after such exposure.

B. Seals to be Investigated

The classes of seals to be investigated were defined as follows and included the following basic material combinations:

Class A-A seal that is accomplished by the fusion of metallic and/or ceramic materials. This will include the fusion of metals by welding, brazing, or soldering; the fusion of ceramic materials under heat or pressure; and the fusion of ceramic materials into a metallic support.

a) Metal to metal (welded, brazed and soldered joints)

(1) Steel to steel
(2) Brass to brass
(3) Aluminum to aluminum

b) Metal to ceramic seals (brazed or solder joints)

(1) Glazed ceramic to steel
(2) Glazed ceramic to Kovar
(3) Unglazed ceramic to steel
(4) Unglazed ceramic to Kovar

Class B - A seal that is accomplished by the fusion, vulcanizing, or adhesion by use of chemical and/or mechanical process of any other material such as thermosetting plastics or elastomers to the metallic case, structure or assembly.

Fused, Vulcanized, or Adhesion (by chemical or mechanical means) Seals- Molded thermosetting plastics such as casting or potting resins as polyesters, asphaltics, etc., which may include such materials as Teflon, Kel-F, and silicones in contact with:

(1) Steel
(2) Brass
(3) Aluminum

Class C - A seal that is accomplished by the use of gaskets, "O" rings, or other similar items which are held in proper relation to the abutting surface by pressure exerted by the use of screws, bolts, or other clamping mediums.

Gasket Seals:

(1) Natural rubber
(2) Neoprene
(3) Asbestos
(4) Lead
(5) Copper

Class D - A seal that is accomplished by having the abutting surface ground, lapped, or polished to produce a precision fit. The mating surfaces are held in intimate contact by means of bolts, screws, or other suitable clamping devices.

Ground, Lapped, or Polished Abutting Surface Seals including Screw Thread Types

(1) Steel to Steel
(2) Brass to brass
(3) Aluminum to aluminum

C. Effect of Environmental Service Conditions

The leakage rate of each of the specimens was to be determined in both directions and expressed in quantitative units such as standard cc/year/inch of seal. In addition to measurement at room conditions, the effect of environmental service conditions of pressure, humidity, temperature cycling and vibration on the leakage rate was also to be determined.

D. Necessity for Quantitative Measurements

One might ask why quantitative measurements are necessary in the first place. Why not simply detect if there is or is not a leak and stop there? There are several reasons why this is not sufficient.

Suppose a leak is detected and from the slight response a very small leak is indicated. One might say that this leak is only a little larger than what the instrument can detect. Since the instrument can detect leaks of x standard cc/year, this leak must be slightly greater than x standard cc/year. What one does not realize is that the detection sensitivity of a given detector varies greatly from time to time.

Suppose a different leak is detected and from the response one can say that it is a "very large" leak. Just how large is "very large"? A value of 950 on an arbitrary scale? This avoids the question and does not tell how many standard cc/year are passing through the leak. Would this same leak measure 950 on the same arbitrary scale three months later?

It is precisely for these reasons that one is unable to obtain quantitative leak meters on the market while many types of leak detectors are readily available. Some manufacturers of leak detectors flatly state that their instruments are detectors and are not meant for quantitative leakage rate measurements.

With a quantitative leak meter it is possible to determine the size of a given leak in quantitative units. How, then, does a quantitative leak meter differ from a leak detector?

While both instruments have a detector which is sensitive to one or more test gases, the quantitative leak meter is calibrated over its entire range of measurement. All variables other than the physical size of the leak are kept constant so this calibration has meaning.

Unless all of these variables are kept constant, the only other recourse is to use a comparison method to measure the size of an unknown leak. This involves comparing the reading obtained with a calibrated leak to the unknown leak, both being measured under the same immediate conditions. This has two disadvantages:

(1) The order of magnitude of the unknown leak should be known before it is measured so the proper calibrated leak may be selected for comparison. Since leakage rate measurements might cover a range from 1 to 100,000 standard cc/year, it might be quite difficult to select, on the first try, the proper size of calibrated leak for comparison.

(2) Two or more measurements might be required for every leakage rate determination.

Once the quantitative leak meter has been calibrated over its entire range, only a single measurement is required for each leakage rate determination. A leak as large as 100,000 standard cc/year can be measured before or after a leak of 1 standard cc/year, without using any calibrated leaks. If there is any doubt as to the accuracy of the measurements, the instrument can be recalibrated over its entire range with a series of calibrated leaks before proceeding.

Measurement of leakage rates with a quantitative leak meter gives an engineering standard to judge improvement in seal design. If the measured leakage rate is higher than the electronic equipment inside the container can tolerate, the component can be rejected or resealed. If the leakage rate is under the "tolerance level", the component can be used as it is. How much leakage can be tolerated, is, of course, a completely different problem which must be determined empirically for each case. Quantitative measurement of the leakage rate therefore permits the use of the most economical seal in each application where an absolute seal is not necessary and where the cost of absolute sealing might be prohibitive.

The evaluation of quantitative leakage rates involved the prior development and validation of Leakage Measurement Apparatus, described in Part I. The Preparation and Specifications for Test Specimens, The Testing Procedures, and Quantitative Results are presented in Part II.

PART I

DEVELOPMENT OF LEAKAGE MEASUREMENT APPARATUS

SECTION I

ANALYSIS OF THE MEASUREMENT OF LEAKAGE RATES

A. General

The leakage rate of a leak of given physical dimensions is not unique. It can have many different values depending on the choice of pressures on both sides of the leak and properties of the gas flowing through the leak. Even the most casual observer is aware that the greater the pressure across a leak, the greater will be the leakage rate. If quantitative measurements are to be made for the purpose of comparing one seal to another, it is necessary that the gas used and the pressure on both sides of the leak be fixed and the same for all measurements. The exact relationship between the leakage rate and the choice of gas and pressures can be seen from analysis of Poiseuille's Law which governs the viscous flow of gases through leaks (Scientific Foundations of Vacuum Technique by Dushman, p. 84).

Where
$$Q = \frac{2.618 \times 10^{-4}}{n} \times \frac{a^4(P_2^{\,2} - P_1^{\,2})}{L}$$

Q = leakage rate in micron liters per second.
n = coefficient of viscosity of the gas in poises.
a = radius of the leak in cm.
L = length of the leak in cm.
P_2, P_1 = pressures on opposite sides of the leak in microns

Proper choice of P_2, P_1, and n will increase the sensitivity and reproducibility of the measurements.

B. Sensitivity

The leaks encountered in a sealed specimen will, of course, not be geometrically shaped in the form of the ideal leak, having a uniform radius while extending perpendicularly through the wall of the container. The gas might meander around a seam in the container and emerge from the other side of the container wall a considerable distance from where it entered. However, for a given size leak there does exist an effective radius, a, and an effective length of leak, L, which are constant.

If $P_2 = P_1$ in the Poiseuille equation, $Q = 0$ and there will be no net leakage through a hole in the container regardless of how large the radius a is. Thus, there must be a pressure differential in order to have the gas flow through the hole. (Note that the leakage rate is not proportional to the pressure differential as it is for molecular flow, discussed in a later section under Analysis of Gas Flow, but is proportional to the difference of the squares of the pressure.) The greater the pressure difference, the larger the leakage rate for a given size leak. Use of a higher pressure differential therefore increases the sensitivity and makes it possible to detect smaller size leaks by increasing the leakage rate above the detection threshold.

The sensitivity to measuring small leakage rates can also be improved by using a test gas with a low coefficient of viscosity. All other factors being constant, the lower the viscosity, n, of the test gas, the larger the leakage rate, Q. However, the test gas chosen must be one to which the detector is sensitive.

A third means of increasing the sensitivity to measuring small leaks is to choose a leakage rate meter having a very low, preferably zero, background indication when no leak is present.

There is another type of sensitivity which the measuring instrument should possess. This is a selective sensitivity which the measuring device should exhibit to the test gas alone, while being insensitive to all other gases or variables which cannot be kept constant. This would keep the leakage rate meter from giving an indication to anything but the test gas passing through a leak in the container.

C. Reproducibility

The pressures, P_2 and P_1, on both sides of the leak and the viscosity, n, of the test gas must be kept constant to obtain reproducible results. If the leakage rate is to be a function of the physical dimensions of the leak alone (a and L for the ideal leak) then the boundary conditions on both sides of the leak must be kept constant.

There is an infinite choice of pressures available for inside and outside the sealed container. Since P_1 and P_2 must be kept constant for all measurements for reproducible results it is desirable to choose pressure standards that are easily reproducible within the accuracy of the measurements. The pressure difference should not be so small that sensitivity suffers. However, it should not be so large that it physically changes the leak or causes a leak in the container where one did not exist before. Since it is desirable to keep to a minimum the time for the leak meter to respond to a leak, it is necessary to keep the mean free path of the test molecules long with respect to the dimensions of the measuring system. In other words, the pressure here should be low enough so that the test gas molecules suffer few collisions with other gas molecules on their way to the detector.

To satisfy these conditions, P_1 should be a vacuum of the order of 1 micron or better. Choice of a vacuum also allows a maximum change in pressure for a given leakage rate of gas leaking into the vacuum, which increases the sensitivity. If P_2 is chosen as 1 atmosphere of test gas, the pressure differential is 1 atmosphere. This pressure differential is sufficient for excellent sensitivity, and pressure conditions are not drastically different from what the components might encounter in actual use.

The vacuum can be reproduced to well within 0.01% of atmospheric pressure. Atmospheric pressure is a convenient standard for establishing P_2 at 1 atmosphere. While there are isolated instances of atmospheric pressure fluctuating by ±5%, the average yearly extreme is less than ± 3%. This would produce up to ± 6% change in leakage rate measurements, well within the estimated accuracy of the leakage rate measurements, Considering that a leakage rate meter might have a range from 1 to 100,000 standard cc/year, this error is insignificant.

Constant viscosity of the test gas is readily obtainable. With normal room temperature variation, the viscosity of hydrogen, for example, can be expected to vary less than ± 1%. This, of course, assumes that all of the air occupying the space surrounding the test specimen is replaced by the test gas at 1 atmosphere. For accurate measurement of the smaller leakage rates, it is necessary that this atmosphere of test gas be established completely and quickly. Flushing out the air with the test gas requires too much time. A more thorough and quicker method is to evacuate the air and let in the test gas at 1 atmosphere at the start of the measurement.

SECTION II

LEAKAGE MEASUREMENT

A. Requirements

Previous experience with several of the seals to be tested indicated that a very wide range of leakage rates was to be measured. Silver solder joints, soft solder joints and "O" ring seals used in former vacuum systems have shown zero leakage as measured on both the mass spectrometer leak detector and hydrogen ion gauge leak detector. On the other hand, asbestos gaskets have had such large leakage rates that it was impossible to sustain the degree of vacuum necessary for leak location with either detector. Because the range of leakage rates was too large for a single leak meter, it was decided to use two leak meters to cover the complete range. Measurements made during the course of this investigation have confirmed the need for a binary system of leak meters. Leakage rates from less than 1 standard cc of air/year to 0.1 standard cc of air/sec. have been measured on this system. The latter leakage rate is 3,000,000 times larger than the former, indicating the extreme range of leakage rates encountered.

B. Comparison of Methods

Many methods are available for the location of leaks in seals. These include the following:

a) Tesla coil for leaks in glass
b) Soap bubble test
c) Thermocouple gauge with ether or acetone
d) Pirani gauge with hydrogen
e) Ion gauge with ether or acetone
f) Halogen leak detector
g) Mass spectrometer leak detector
h) Hydrogen ion gauge leak detector.

While many of these methods are excellent for detecting and locating leaks, most of them would be unsuitable for the quantitative measurement of leakage rates of the specified seals.

The Tesla Coil produces a concentrated spark at the point of leakage into the evacuated glass system. It is neither quantitative nor can it be used to test seals of metal construction.

The soap bubble test is a simple, sensitive method for locating leaks in all types of seals. The usual procedure is to pressurize the inside of the component with several atmospheres of any convenient gas. Soap solution

is then painted over all suspected areas on the outside of the component with a brush, and bubbles form at points of leakage. The sensitivity of this method is often underestimated. With sufficient pressure, it is possible to locate leaks only 100 times larger than those just detectable on the Mass Spectrometer Leak Detector. Unfortunately, this method cannot be used for the quantitative measurement of leakage rates.

The thermocouple gauge and the Pirani gauge are used primarily to measure pressures below 0.1 mm. of Hg. Neither is damaged by exposure to atmospheric pressure. The thermocouple gauge is sensitive to ether and acetone vapors while the Pirani gauge is sensitive to hydrogen. Leaks can be located by spraying the suspect areas with the test liquid or gas. Any change in the pressure of the system is evidence of a leak. However, neither method is very sensitive nor are the results quantitative.

The ion gauge is also primarily a pressure measuring device, measuring pressures below 0.001 mm. of Hg. It cannot be operated at pressures higher than this for the filament would rapidly burn out. Very small leaks can be located by spraying the suspect areas with ether or acetone and noticing the change in pressure, if any. This method is very sensitive for locating small leaks but is not suitable for measuring large leaks which might raise the pressure sufficiently to burn out the filament. While the ion gauge could be used for measuring only the smaller leaks, this does not insure against a small leak suddenly becoming large enough to burn out the filament. In addition, the gauge does not have a selective sensitivity to just one gas which makes it possible for gases other than the test gas flowing through the leak to affect the results.

The halogen leak detector is primarily a leak locating device. It operates on the principle that the rate of ion emission from a heated platinum electrode increases very markedly when vapors of compounds containing a halogen strike the electrode surface. According to the Consolidated Vacuum Corporation, their Type LD-01 Halogen-Sensitive Leak Detector is capable of very high sensitivity but is primarily intended to detect and locate leaks rather than to measure leakage rates. Another manufacturer, the General Electric Company, states that their Type H Leak Detector is capable of detecting leaks as small as 1/100 oz. of Freon/year (about 50 standard cc/year) and that:

> "The leak detector is not a quantitative device and can give only an approximate indication of the size of the leak. Due to an inherent variation in the equipment, the sensitivity will not remain sufficiently constant to permit quantitative determination of leak size. In general, the detector is not useful in vacuum systems. The sensitivity of the detector is critically dependent upon the temperature of the sensitive element and it is extremely difficult to maintain constant temperature under vacuum conditions".

Because the manufacturers of both halogen leak detectors state that their instrument is not meant for quantitative measurements, this method was not considered further.

The mass spectrometer leak detector responds to only a single test gas, usually helium. When helium is passed over a leak, some of it, along with any other gas present, enters the vacuum system and becomes ionized by electron emission from the heated filament of the mass spectrometer tube. All the ions are accelerated by an electric field but only helium ions are permitted to strike the ion collector by proper adjustment of the magnetic field. The helium ion current is then amplified and read on a meter, the reading being proportional to the helium leakage rate.

The mass spectrometer leak detector is capable of detecting leaks as small as 0.03 standard cc of helium/yr. Under identical conditions, this is equivalent to an air leakage rate of 0.01 standard cc of air/yr., assuming molecular flow. Unfortunately, the range over which the maximum sensitivity of the instrument can be used is limited. This results because the pressure inside the mass spectrometer tube should be kept below 0.001 mm. of Hg at all times in order to keep the filament, heated to incandescence, from burning out. This can only be accomplished by throttling down the leak detector, which prevents a large portion of the helium passing through the leak from reaching the mass spectrometer tube. The sensitivity is thereby reduced, limiting the instrument's usefulness wherever an extreme range of leakage rates is to be measured. Additional disadvantages are its high initial cost, about $5,000, and the complexity of the equipment to be serviced.

The hydrogen ion gauge leak detector utilizes a highly evacuated ionization gauge tube which responds to hydrogen but not to other gases or vapors. The evacuated tube is sealed off by means of a palladium window. When the palladium is heated, it has the unique property of becoming permeable to hydrogen. Thus, any hydrogen passing through a leak into the vacuum system enters the ion gauge through the palladium. Here the hydrogen becomes ionized by electron emission from a heated cathode, the positive ions going to an ion collector. The hydrogen ion current is then amplified and read on a meter, the reading being proportional to the hydrogen leakage rate.

The hydrogen ion gauge (RCA-1945) is capable of detecting leaks as small as 0.4 standard cc of hydrogen/year. Under identical conditions, this is equivalent to an air leakage rate of 0.1 standard cc of air/yr., assuming molecular flow. Because of the selective action of the palladium, the gauge can have a sensitivity corresponding to a system evacuated to 10^{-7} mm. of Hg without evacuating any lower than 10^{-3} mm. of Hg. This high sensitivity can be obtained on systems using rotary vacuum pumps and does not require the use of diffusion pumps. Quantitative measurements of leakage rates can be made at hydrogen pressures in excess of 10^{-2} mm. and the gauge is not physically damaged by accidental exposure to atmospheric pressure. This is especially important where a wide range of leakage rates is to be measured, some of which might be or might suddenly become very large. The electronic circuitry of the hydrogen ion gauge is relatively simple and the cost of the complete unit less than $1,000.

Of all the methods considered, only the mass spectrometer leak detector and the hydrogen ion gauge leak detector had both sufficient sensitivity for the measurements to be made and were capable of quantitative measurements. While the former is unequaled in its sensitivity for detecting and locating minute leaks, the limiting sensitivities of both detectors differ by less than one standard cc/year, being 0.01 and 0.1 standard cc of air/yr., respectively.

Since previous experience with several of the seals to be tested indicated that two leak meters would be needed to cover the complete range of measurements, it was necessary that the ranges of both instruments meet and preferably overlap. Without knowing at that time the exact range of measurement of both leak meters finally used, it became a necessity to choose leak meters having the widest possible range. The fact that the mass spectrometer is inherently limited in its range of measurement because of its exposed, heated filament, was considered a sufficient reason for not employing this method for the specified measurements. Cost and complexity of the equipment were also considered in choosing the hydrogen ion gauge method for measurement of the smaller leaks. This leakage rate meter designated as the High Sensitivity Leak Meter, is an integral part of the Binary Leak Meter specially constructed for this work.

The rate of pressure increase method was originally adapted for measurement of leakage rates too large to be measured on the hydrogen ion gauge. Used frequently in the calibration of calibrated leaks, this method was unsatisfactory for the required measurements because of the high outgassing rate of many of the specimens. The method finally used for measurement of the larger leakage rates is an adaptation of the method used for measuring the pumping speed of vacuum pumps, (Dushman, Scientific Foundations of Vacuum Technique, p. 159). The leakage rate is measured directly from the rate at which a water plug travels in a calibrated capillary which is connected in series with the specimen to an evacuated manifold. This leakage rate meter is called the Gross Leak Meter and constitutes the other half of the Binary Leak Meter.

SECTION III

DESIGN OF THE BINARY LEAK METER

A. General

The Binary Leak Meter consists of two meters, a High Sensitivity Leak Meter and a Gross Leak Meter, so designated because of their differing sensitivities. Each of these instruments is a complete integral apparatus and both are mounted compactly upon a single laboratory bench. The High Sensitivity Leak Meter measures leaks which have an air leakage rate from 1 standard cc/year to 100,000 standard cc/year. The Gross Leak Meter measures leakage rates from 15,000 standard cc of air/year to 3,000,000 standard cc of air/year. Since the High Sensitivity Leak Meter is capable of measuring such large leaks, the Gross Leak Meter was usually used for leakage rates larger than 100,000 standard cc of air/year.

B. Choice of Constructional Materials

Both leak meters measure the leakage rate through seals with 1 atmosphere pressure on one side of the seal and a vacuum of the order of 1 micron (10^{-3}mm.) of Hg on the other side. Since a vacuum is to be maintained, it is necessary that there be no leakage into the vacuum system and that outgassing be reduced to a minimum. Leakage can occur when air penetrates either through the vacuum system walls by porosity, or through the system joints or mechanical seals. The evolution of gas within the system from wall pores, evaporation or degassing of substances of high vapor pressure is generally termed "outgassing". Use of proper construction techniques is important in eliminating leakage. Proper selection of materials and precautions involved in the use and maintenance of the system reduce outgassing to a minimum.

A metal vacuum system was chosen rather than glass because of the more sturdy construction and the ease of disassembly for repair or cleaning. Castings were avoided because they are often porous. Steel was not selected because the oxides and hydroxides forming on the surface are highly hygroscopic and take up water on exposure to moist air. This causes outgassing in the vacuum system and greatly increases the time required to pump down to the required vacuum. Aluminum was not used because it is somewhat difficult to braze or solder to other metals. In addition, certain essential parts of the vacuum system such as the electrical seals and bellows were not of aluminum construction.

Brass was chosen primarily because of the ease in obtaining vacuum tight joints by soldering or brazing. It is suitable for vacuum systems at room temperature for the vapor pressure of the zinc in the brass does not become appreciable except at higher temperatures. In addition, it is not hygroscopic. "O" rings were used at the system joints for ease in disassembly. All "O" ring catalog numbers correspond to Linear Incorporated's designations.

C. Design of the High Sensitivity Leak Meter

The High Sensitivity Leak Meter, shown in Figure 1, consists of the following basic components:

1) RCA-1945 hydrogen ion gauge
2) Cold trap
3) Hydrogen generator
4) Thermocouple gauge
5) Kinney vacuum valves
6) Hoke vacuum valves
7) Vacuum manifold
8) Forepumps
9) Hydrogen ballast container
10) Specimen container

The assembly drawing of the High Sensitivity Leak Meter is shown in Figure 2. The function and design of each of these components will be discussed following a brief explanation of the operation of the leak meter.

A simplified schematic showing the path of hydrogen through the leak meter is shown in Figure 3. Briefly, hydrogen enters the specimen container, passes through any leak in the specimen and enters the vacuum manifold through open Hoke valve 2. Once the hydrogen is in the manifold, it passes through open valve B, through the cold trap and enters the ion gauge through the heated palladium window. Here the hydrogen is ionized by an electron stream and the positive hydrogen ions go to the negatively charged ion collector. This increase in ion current, after amplification, can be read directly on the leak meter.

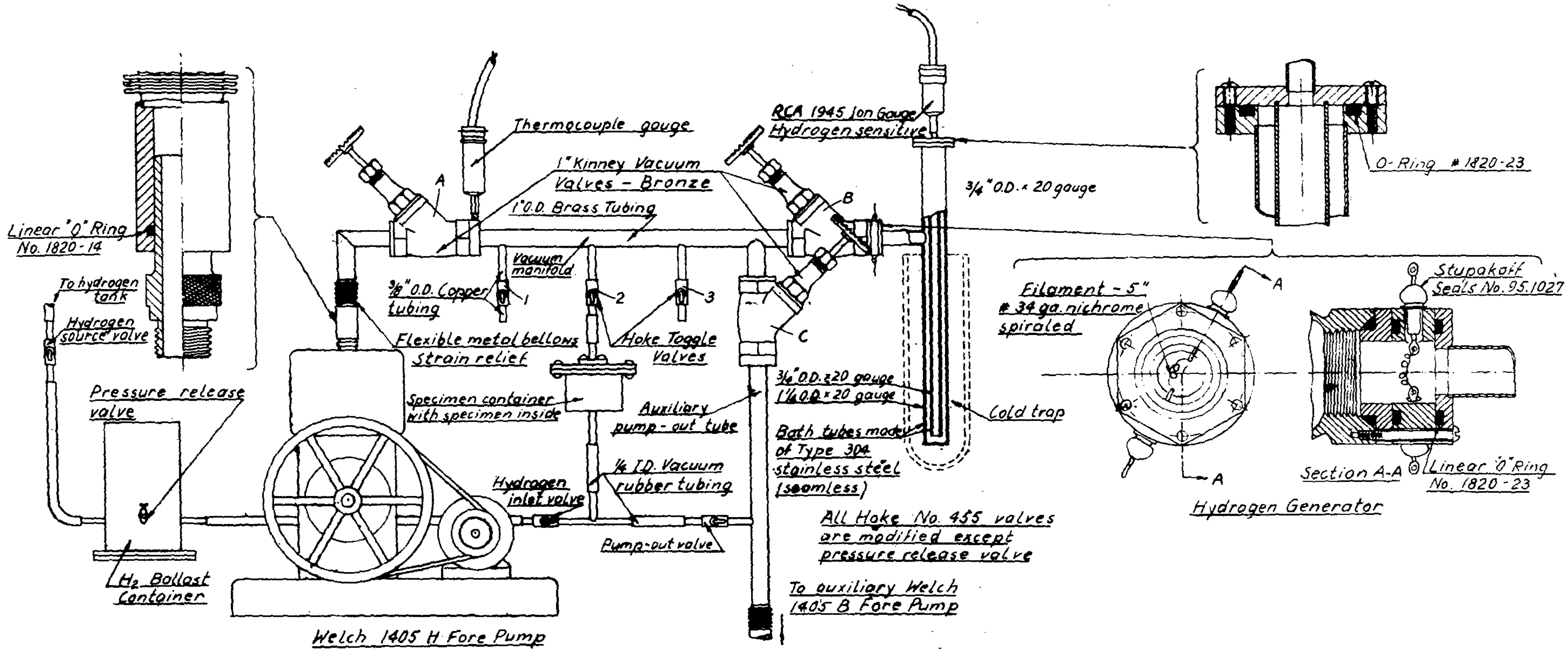
1) RCA-1945 hydrogen ion gauge

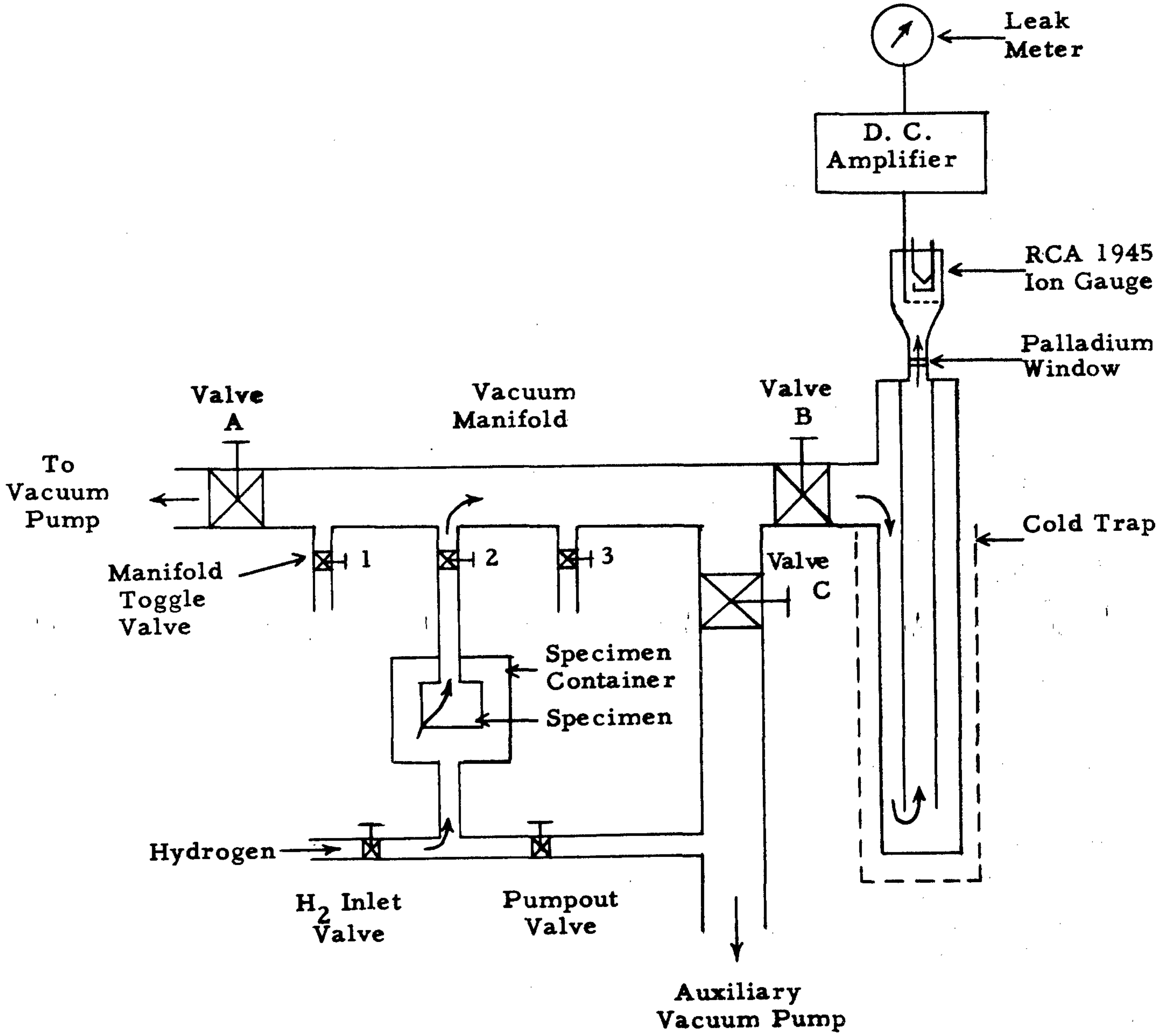
The hydrogen ion gauge is soft soldered to the vacuum system at the top of the cold trap. Inside the gauge are an indirectly heated cathode and an ion collector, both sealed off from the vacuum system by a thin palladium window. This window is a vacuum tight seal when the palladium is cold, but serves as a membrane permeable to hydrogen when heated. This allows only hydrogen to pass through the palladium, when it is heated, into the gauge. Electrons emitted from the cathode, strike the palladium and heat it up. The electron current and the voltage between the cathode and palladium window are adjusted so that the power dissipation at the palladium is 6 watts. With 6 watts dissipation, the palladium is maintained at the proper temperature which is about 800°C.

Figure 1. The High Sensitivity Leak Meter.

Figure 2

Assembly Drawing of High Sensitivity Leak Meter





Run	Valves Open	Valves Closed
Timed	2, B, H_2 inlet valve	1, 3, A, C, pumpout valve
Equilibrium	2, A, B, H_2 inlet valve	1, 3, C, pumpout valve

Figure 3. Path of Hydrogen Through High Sensitivity Leak Meter

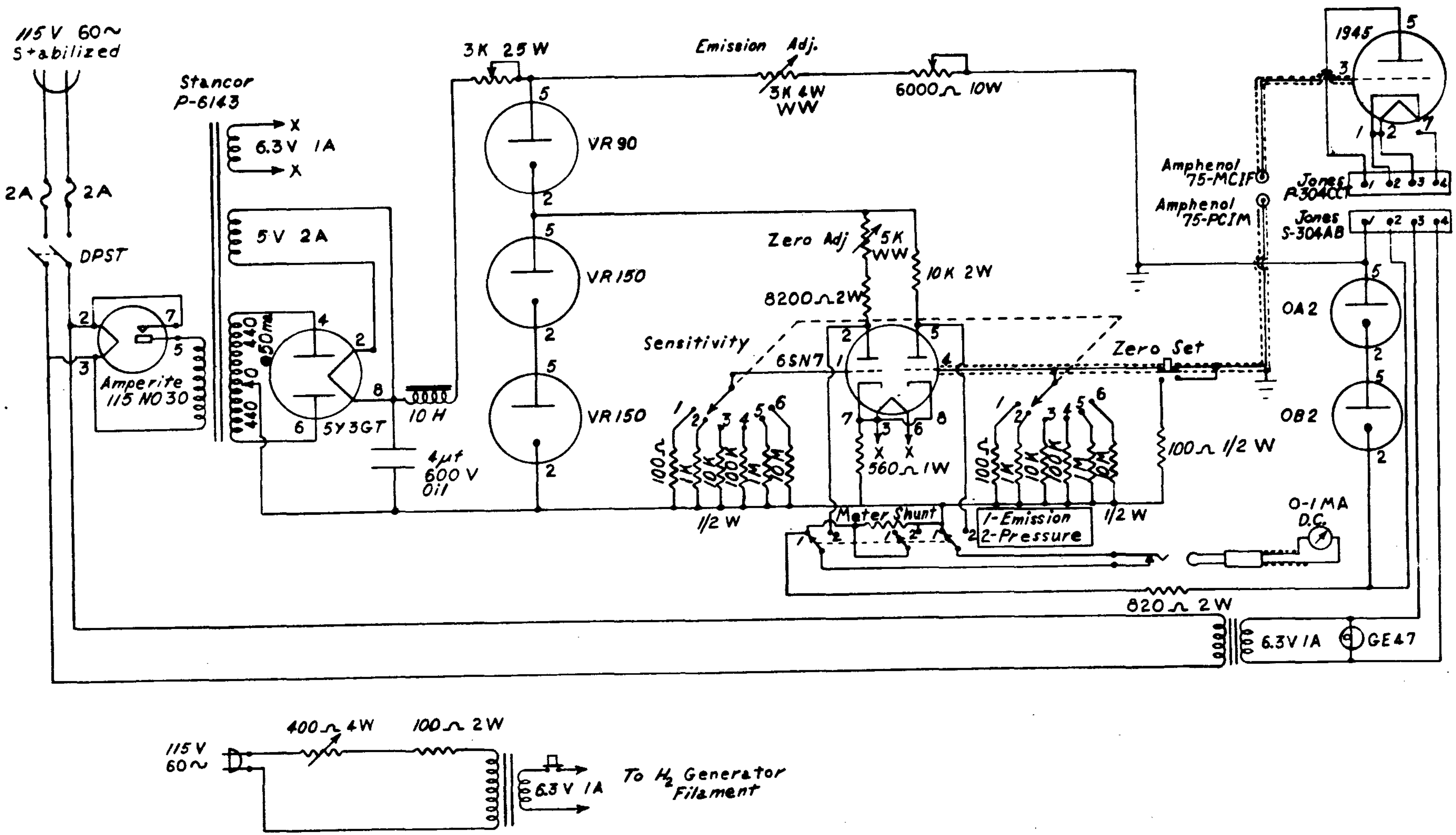
The hydrogen ion gauge control circuit maintains the proper voltages on the ion gauge electrodes, keeps the plate dissipation at 6 watts and amplifies the ion current sufficiently to be read on a meter. An electrical schematic of the control circuit is shown in Figure 4. This circuit has the unique property of maintaining the power dissipation at 6 watts regardless of the amount of hydrogen in the tube. Test results show conclusively that the impedance of the hydrogen ion gauge tube is a function of the amount of hydrogen in the tube. Both wattage and emission current should be held as constant as possible so that the only variable is the concentration of hydrogen.

The control circuit consists of a power supply, constant wattage regulator, bridge amplifier, and a hydrogen generator circuit. The function of the latter will be explained in (3) below.

The power supply is conventional in that it utilizes a 5Y3GT rectifier with a condenser input filter. An Amperite 115N030 applies the plate voltage to the RCA 1945 about 30 seconds after the switch is turned on, the heater voltage being applied immediately. The manufacturer recommends that heater voltage be applied first. The two VR150 voltage regulator tubes stabilize the supply voltage for the bridge amplifier at 300 volts. The additional VR90 voltage regulator tube giving a supply voltage of 390V for the RCA 1945 is not arbitrary but required by the design of the constant wattage circuit.

The greatest change in wattage and also emission occurs when hydrogen suddenly enters the gauge and decreases the tube impedance. A very simple circuit, instantaneous in response, has been designed to hold the wattage constant to well within 1% during the run. The wattage variation with the emission regulation circuit previously used was 10%. In addition, the constant wattage circuit holds the emission more constant during the run than the former emission regulation circuit by a factor of two. Emission regulation does not work satisfactorily with sudden changes in tube impedance because of the thermal lag of the indirectly heated cathode. The temperature of the cathode cannot be changed sufficiently fast to counteract a change in emission caused by a rapidly changing tube impedance.

Figure 4. Hydrogen Ion Gauge Control Circuit.



Constant wattage, independent of the changing tube impedance, can be obtained by proper choice of the plate supply voltage and series resistance to the gauge. It can be shown mathematically that this series resistance should be equal to the tube impedance. This result can be obtained by differentiating the equation for the wattage across the tube with respect to the tube impedance and setting the resultant equation equal to zero. A series resistance equal to the tube impedance requires that the total or plate supply voltage be twice that across the tube. Since the RCA-1945 ion gauge used required a plate voltage of 194 volts for a 6 watt plate dissipation, three voltage regulator tubes totaling 390 volts were used for the plate supply voltage. The series resistance consists of two resistors, the Emission Adjust, and the adjacent 6000 ohm resistor for coarse adjustments. The 6 watt value is obtained by adjusting the emission current to a value such that the product of this current and the plate voltage is 6 watts. At no time should the wattage be allowed to exceed 7 watts.

The exact value of emission current and plate voltage required to obtain 6 watts may differ slightly from tube to tube. For example, the RCA-1945 used when the circuit was designed had an emission current of 31 milliamperes when the plate voltage was 194 volts, giving the required 6 watts plate dissipation. The RCA-1945 presently in use has an emission current of 29 milliamperes when the plate voltage is 206 volts, also giving 6 watts plate dissipation. The current is set at the appropriate value by the "Emission Adjust" control while observing the meter with the meter switch in "Position 1". The resistance of the meter shunt is chosen such that the meter reads 50 milliamperes full scale with the meter switch in this emission position. The constant wattage circuit has functioned equally well for both tubes.

The OA2 and OB2 voltage regulator tubes, connected between the plate and cathode of the ion gauge, protect the latter from excessive voltages. These tubes fire and limit the voltage at slightly over the maximum voltage of 250 volts allowable across the RCA-1945. These tubes prevent the full plate supply voltage of 390 volts from being applied to the ion gauge before it starts conducting. During regular operation of the gauge, these tubes have no effect for the plate voltage is around 200 volts, well below their firing voltage.

The bridge amplifier consists of a single 6SN7 with a 1 milliampere full scale meter between the plates. The amplifier and meter are used to measure quantitatively the minute ion collector current. The circuit is designed so that one volt on the grid produces full-scale deflection of the meter. An increase of only 0.001 microampere can be accurately read on the meter with the selector switch in the highest sensitivity position. The "Sensitivity" switch has 6 positions, "Position 6" being the most sensitive. Each change of position of the "Sensitivity" switch changes the scale a factor of 10. The full scale meter readings from "Position 6" to "Position 1" are 1, 10, 100, 1000, 10,000, and 100,000, respectively.

To obtain more accurate readings, the 0-1 milliampere meter was removed from the chassis and used as a remote meter. It was found that normal chassis heating changed the meter calibration slightly when measuring the emission current. The plate lead of the RCA-1945 is grounded to the chassis because the palladium window is connected electrically to the outside of the tube. Grounding at this point insures that there is no voltage between chassis and ion gauge tube, eliminating all possibility of shocks. A constant voltage transformer is used to stabilize the line voltage.

2) Cold Trap

The cold trap protects the palladium window of the hydrogen ion gauge from contamination by trapping out condensible vapors before they reach the tube. All gases and vapors must pass to the bottom of the trap before they can enter the 3/4" tubing which leads to the gauge. The vapors condense on the walls of the trap which are maintained at liquid nitrogen temperatures. Many of the organic vapors come from the pump oil. The presence of oil vapor on or near the palladium window will cause an ion current even when hydrogen is not present in the manifold.

The cold trap, designed to facilitate disassembly for cleaning, is made of Type 304 stainless steel tubing because of its very low coefficient of thermal conductivity. The tubing is chosen as thin as possible to minimize heat conduction into the trap. This construction reduces the rate of evaporation of the liquid nitrogen. Seamless tubing is used to insure its vacuum tightness. Annealed tubing is used for the same reason because minute cracks may form at the silver solder joints with unannealed tubing. The diameters of the two concentric tubes have a ratio of 0.6 which is consistent with good vacuum trap design. The 3/4" diameter tubing and the hydrogen ion gauge are soldered into opposite sides of the same flange, the former being silver soldered. Organic vapors from the "O" ring sealing on this flange are trapped from the ion gauge by this construction. The side arm of the trap is also of stainless steel to minimize heat conduction.

3) Hydrogen Generator

The hydrogen generator is used to test and maintain the maximum sensitivity of the hydrogen ion gauge. It consists of a Nichrome filament inside and electrically insulated from the vacuum system. When heated to 750° - 1100°C., it decomposes pump oil vapors in the system, forming hydrogen in the process.

The hydrogen generator is shown in detail in Figure 2. It is the small unit immediately to the left of the cold trap side arm flange Two Stupakoff glass-Kovar seals are soft soldered into the side of the hydrogen generator to provide a vacuum tight, electrically insulated connection. The unit is short in length to facilitate replacement of the filament. The temperature of the Nichrome at the terminals is low enough to permit soft

soldering to the terminals. The "O" ring groove design is such that the generator can be removed and the system assembled without it, if desired. The hydrogen generator is a very convenient test source of hydrogen to facilitate checking the operation of the gauge.

The hydrogen generator circuit for applying voltage to the Nichrome filament is shown at the lower part of Figure 4. A push button switch closes the circuit and applies voltage to the filament. The 400 ohm rheostat allows adjustment of this voltage for maximum filament life.

4) Thermocouple Gauge

The thermocouple gauge serves as a monitor of the manifold pressure so that the valve to the ion gauge is not opened until a predetermined pressure exists. The control circuit for the National Research Corp. Type 501 Thermocouple gauge is shown in Figure 5. The current through the filament is kept constant so that the temperature of the thermocouple junction depends only on the thermal conductivity of the gas present. The thermal conductivity, in turn, depends on the pressure, so that the pressure can be measured as a function of thermocouple current. The latter is read on a 200 microampere meter with a total meter resistance of 70 ohms to correspond to the current readings on the manufacturer's calibration curve of current vs. pressure. The gauge is soft soldered into the manifold flange. A hole drilled radially from the gauge leads to the inside of the vacuum manifold.

5) Kinney Vacuum Valves

Three one inch Kinney vacuum valves are used on the High Sensitivity Leak Meter. The valve next to the cold trap isolates the ion gauge from the rest of the system during specimen pump down when the manifold pressure is high. This is necessary to prevent the decrease in sensitivity which results when the palladium becomes oxidized. The valve is opened only after the thermocouple gauge indicates that a sufficient vacuum exists. The two other valves, one leading to each forepump, are needed to shut off the pumps during the timed runs. These valves have been modified to take standard "O" rings. The modification is shown at the top in Figure 6.

Figure 5. Schematic Diagram Thermocouple Gauge Control Circuit

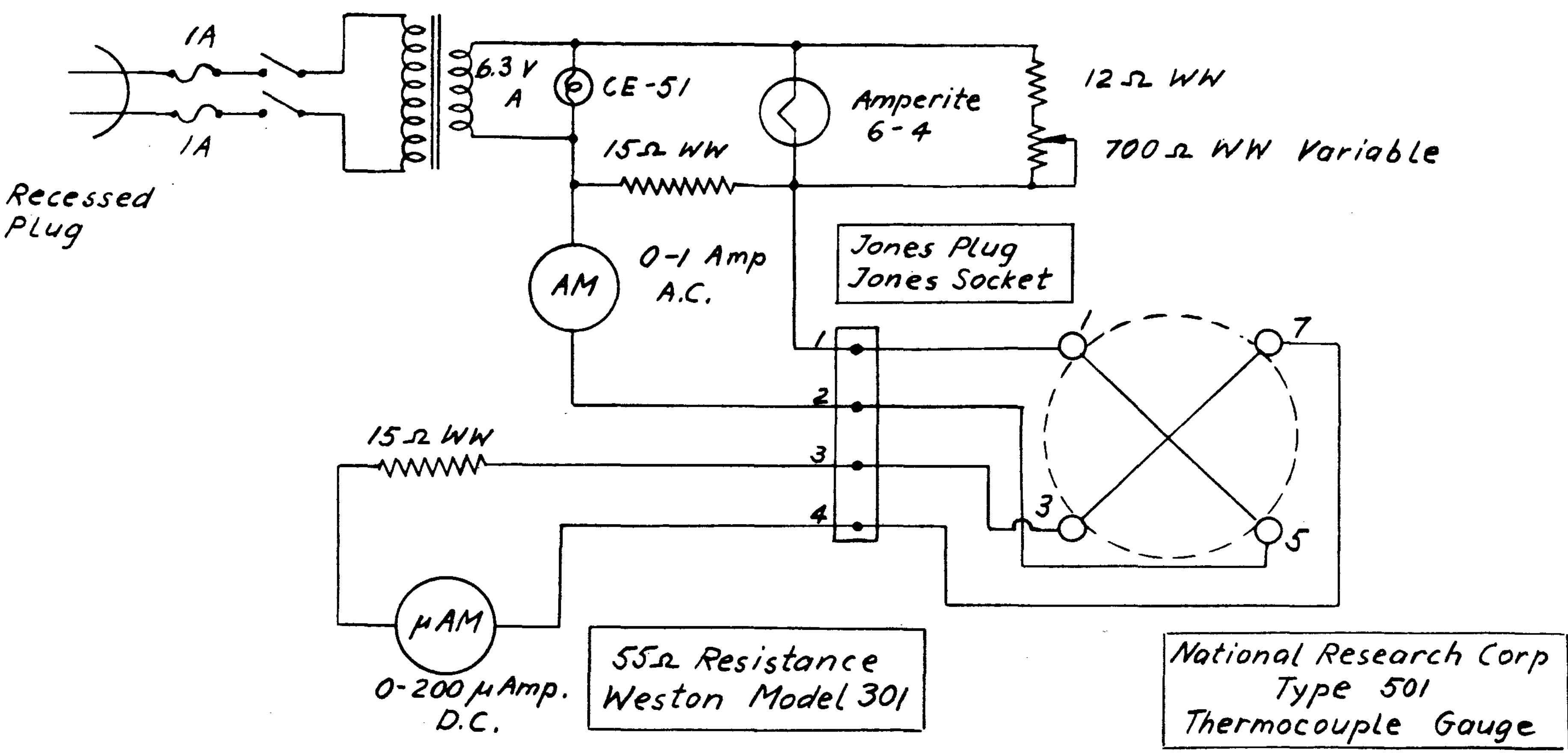
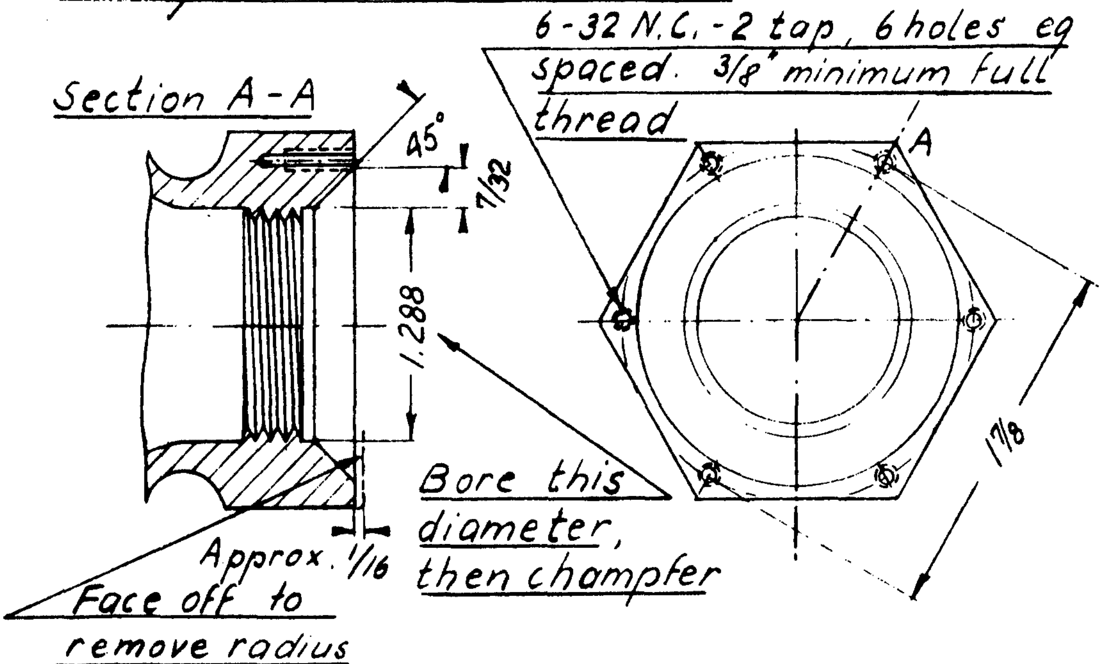


Figure 6

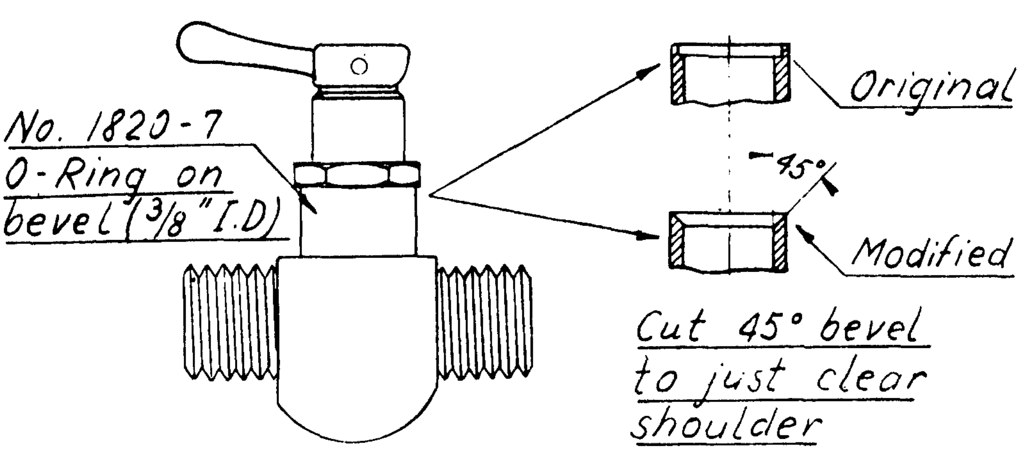
Vacuum Valve Modifications

Kinney 1" valve modification



This modification applies to both ends of valve

Hoke No. 455 valve modification



6) Hoke Vacuum Valves

Hoke No. 455 toggle valves are used exclusively throughout the rest of the leak meter. Experience has shown that toggle valves are more reliable than needle valves. All the toggle valves except the pressure release valve were modified to make the valves vacuum tight on both sides. These valves were disassembled, the bodies beveled, and reassembled with an "O" ring inserted on the body of the valve. Details of the modification are shown in Figure 6. Copper tubing, 3/8" O.D., is silver soldered into both ends of the valves.

Three of the valves are silver soldered to the vacuum manifold. The center valve is used to evacuate the specimen. The valves on each side serve as a convenient source of vacuum. The pumpout valve, silver soldered to the auxiliary pumpout tube, is used to evacuate the specimen container. The hydrogen inlet valve lets hydrogen into the evacuated specimen container at the start of the run. The pressure release valve on the hydrogen ballast container is used momentarily at the start of the run to release excess hydrogen, insuring one atmosphere of hydrogen in the specimen container. This valve does not require modification because only one side of the valve needs to be vacuum tight. The hydrogen source valve keeps more hydrogen from entering the hydrogen ballast container when the excess pressure is released. It also permits evacuation of the ballast container without pumping on the regulator gauge of the hydrogen tank. Connections to all valves were made with 1/4 inch I. D. vacuum rubber tubing.

7) Vacuum Manifold

The vacuum manifold is constructed of one inch diameter seamless brass tubing, about 18 inches long. Brass flanges were silver soldered to both ends. "O" rings in the flanges provide vacuum tight joints while facilitating quick disassembly for cleaning. The manifold diameter was made large enough not to restrict pump down, yet small enough to keep the volume to a minimum to increase the effective sensitivity of the 1945 ion gauge.

8) Forepumps

Only mechanical vacuum pumps, frequently called forepumps, are required for use with the hydrogen ion gauge. Pressures of the order of one micron and less are obtainable. At this pressure, the mean free path of hydrogen is large in comparison to the physical dimensions of the system. This promotes rapid response of the leak meter to leakage. The use of two forepumps on the High Sensitivity Leak Meter reduces pump down time to a minimum. The only physical difference between the two pumps is the speed at which they operate.

The Welch 1405H forepump has a slower pumping speed but has a higher ultimate vacuum. It is used on the vacuum manifold where the vacuum requirements are highest. Its slower pumping speed also reduces the amount of hydrogen it pumps away from the hydrogen ion gauge on the "equilibrium runs" when Valve A is wide open. This is helpful in giving a sufficiently large meter indication for leaks slightly larger than can be measured on "timed runs". Timed and equilibrium runs are explained in the section on calibration.

The Welch 1405B forepump has a faster pumping speed than the 1405H but does not produce as good a vacuum. Its faster pumping speed is advantageously used in pumping out the specimen container, where ultimate vacuum is not important.

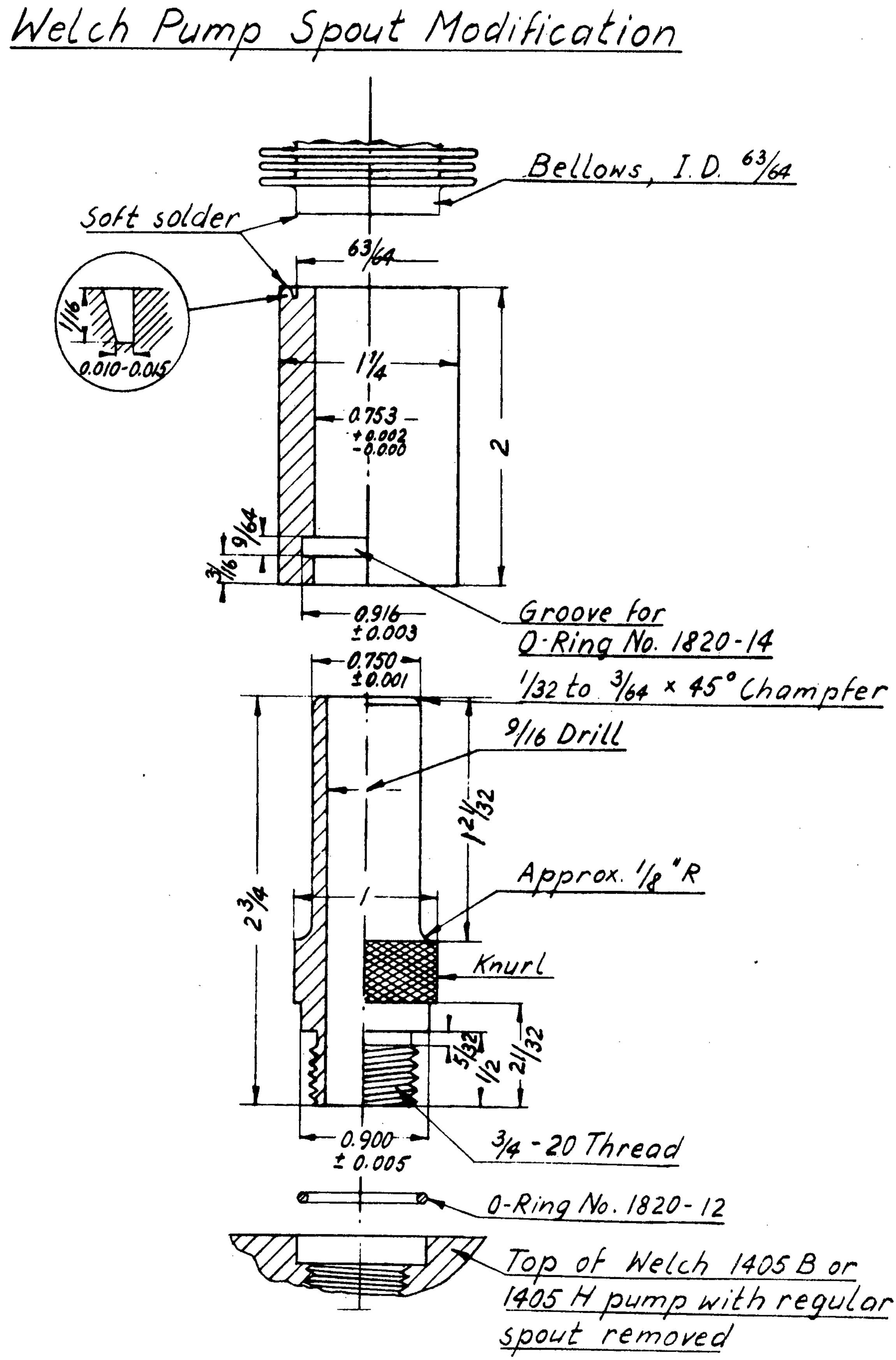
Both pumps are attached to the leak meter by means of a pump adaptor and a flexible metal bellows. Rubber tubing is not used because it readily absorbs hydrogen and increases the hydrogen background. The bellows provide the necessary strain relief, minimizing the pump vibration. The pump spouts of both pumps have been replaced by a pump adaptor as shown in Figure 7. The brass pump adaptor screws in just as the regular pump spout but sealing between the pump adaptor and pump is accomplished by a No. 1820-12 "O" ring. The pump adaptor should only be tightened snugly since no stop is provided to protect the "O" ring from over-compression. A small brass cylinder, soft soldered to the metal bellows and containing a No. 1820-14 "O" ring slips over the pump adaptor for easy disassembly.

9) Hydrogen Ballast Container

The hydrogen ballast container provides a pressure stabilized, one atmosphere supply of hydrogen during the run. The container is cyllindrical in shape, consisting of a short length of four inch diameter brass tubing with an "O" ring flange and removable cover on one end and a brass cover, silver soldered on the other. Two short lengths of 3/8 inch copper tubing are silver soldered to the sides to form an inlet and outlet for the hydrogen. A Hoke No. 455 valve is silver soldered to the front to serve as a pressure release valve.

The container is vacuum tight and can be evacuated before filling with hydrogen at slightly over one atmosphere. The hydrogen pressure is reduced to one atmosphere by momentarily opening the pressure release valve at the start of the run. The ballast container keeps the hydrogen pressure at one atmosphere throughout the run since the volume of hydrogen passing through the leak is negligible compared to that of the ballast container.

Figure 7


Welch Pump Spout Modification
Bellows, I.D. 63/64
Soft solder
63/64
1/16
0.010-0.015
1 1/4
0.753 +0.002 -0.000
2
9/64
3/16
0.916 ±0.003
Groove for O-Ring No. 1820-14
0.750 ±0.001
1/32 to 3/64 × 45° Champfer
9/16 Drill
1 21/32
Approx. 1/8"R
2 3/4
1
Knurl
5/32
1/2
21/32
0.900 ± 0.005
3/4 - 20 Thread
O-Ring No. 1820-12
Top of Welch 1405 B or 1405 H pump with regular spout removed

10) Specimen Container

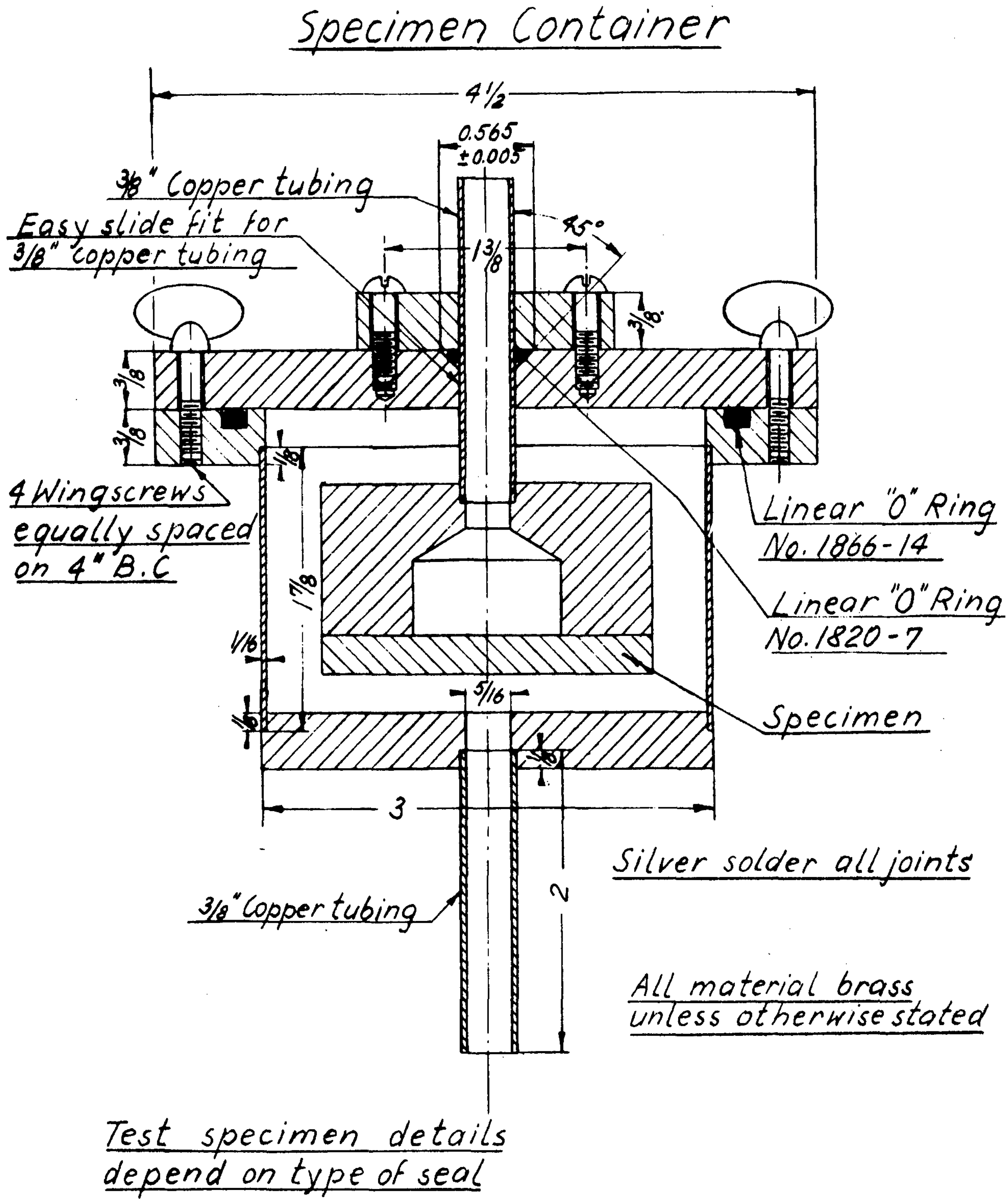
The specimen container provides the proper pressure boundary conditions around the outside of the specimen. The specimen is positioned inside the specimen container as shown in Figure 8 regardless of whether leakage into or out of the specimen is being measured.

If in-leakage is to be measured, hydrogen at one atmosphere is introduced into the specimen container surrounding the specimen. In this case, the inside of the specimen is evacuated by connecting the specimen tube to the manifold toggle valve. If there is a leak in the specimen, hydrogen can pass through into the inside of the specimen and into the leak meter.

If out-leakage is to be measured, the specimen container with the specimen inside is turned over, reversing the hydrogen and vacuum leads. In this case the outside of the specimen is evacuated by connecting the specimen container tube to the manifold toggle valve. Hydrogen at one atmosphere is admitted to the inside of the specimen. If there is a leak in the specimen, hydrogen passes through to the outside of the specimen and into the leak meter.

The specimen container is designed as a vacuum tight enclosure for the specimens. Wing screws and flanges are provided for quick assembly and disassembly of the container. "O" rings are used to seal the specimen container at the cover and around the specimen tube.

Figure 8



Specimen Container
4 1/2
0.565 ±0.005
3/8" Copper tubing
Easy slide fit for 3/8" copper tubing
45°
1 3/8
3/8
3/8
3/8
4 Wingscrews equally spaced on 4" B.C
1/8
1 7/8
1/16
1/16
5/16
Linear "O" Ring No. 1866-14
Linear "O" Ring No. 1820-7
Specimen
1/8
3
2
3/8" Copper tubing
Silver solder all joints
All material brass unless otherwise stated
Test specimen details depend on type of seal

D. Design of the Gross Leak Meter

The Gross Leak Meter shown in Figure 9 consists of the following basic components:

1) Forepump
2) Vacuum manifold
3) Hoke vacuum valves
4) Specimen container
5) Capillary tubes
6) Water plug blow back tube

The assembly drawing of the Gross Leak Meter is shown in Figure 10. The function and design of each of these components will be discussed following a brief explanation of the operation of the leak meter.

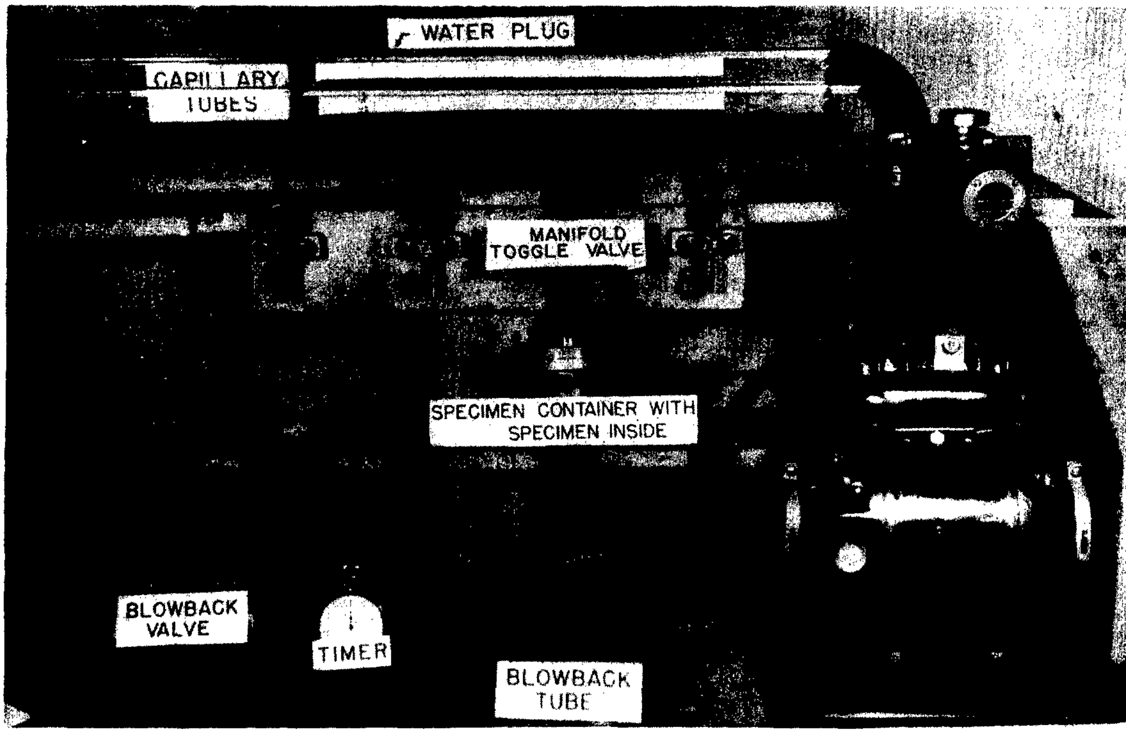
A simplified schematic showing the path of air through the leak meter is shown in Figure 11. After insertion into the specimen container, the specimen to be tested is evacuated by connecting to the vacuum manifold. All air leaking into the specimen first passes through the glass capillary tube. The rate of movement of a small water plug in the capillary is a direct measure of the leakage rate of the specimen.

1) Forepump

A Welch 1405B forepump is used to provide a vacuum on one side of the seals to be tested. It was chosen primarily because of its high pumping speed; the ultimate vacuum required need be no better than a few mm. of Hg. Its high pumping speed of 58 liters/minute reduces pump down time to less than a minute for the specimens tested.

2) Vacuum Manifold

The vacuum manifold is constructed of four inch diameter brass tubing, sealed at one end by a 1/2 inch Lucite cover on a brass, "O" ring flange. The other end is connected to the forepump with 13/16 inch I.D. vacuum rubber tubing. The diameter of the manifold is larger than necessary, being originally designed for the rate of pressure increase method. The only modification required was the replacement of the Philips gauge cover with the Lucite cover. In changing from the latter procedure to the procedure finally used a one inch diameter manifold is adequate.


WATER PLUG
CAPILLARY
TUBES
MANIFOLD
TOGGLE VALVE
SPECIMEN CONTAINER WITH
SPECIMEN INSIDE
BLOWBACK
VALVE
TIMER
BLOWBACK
TUBE

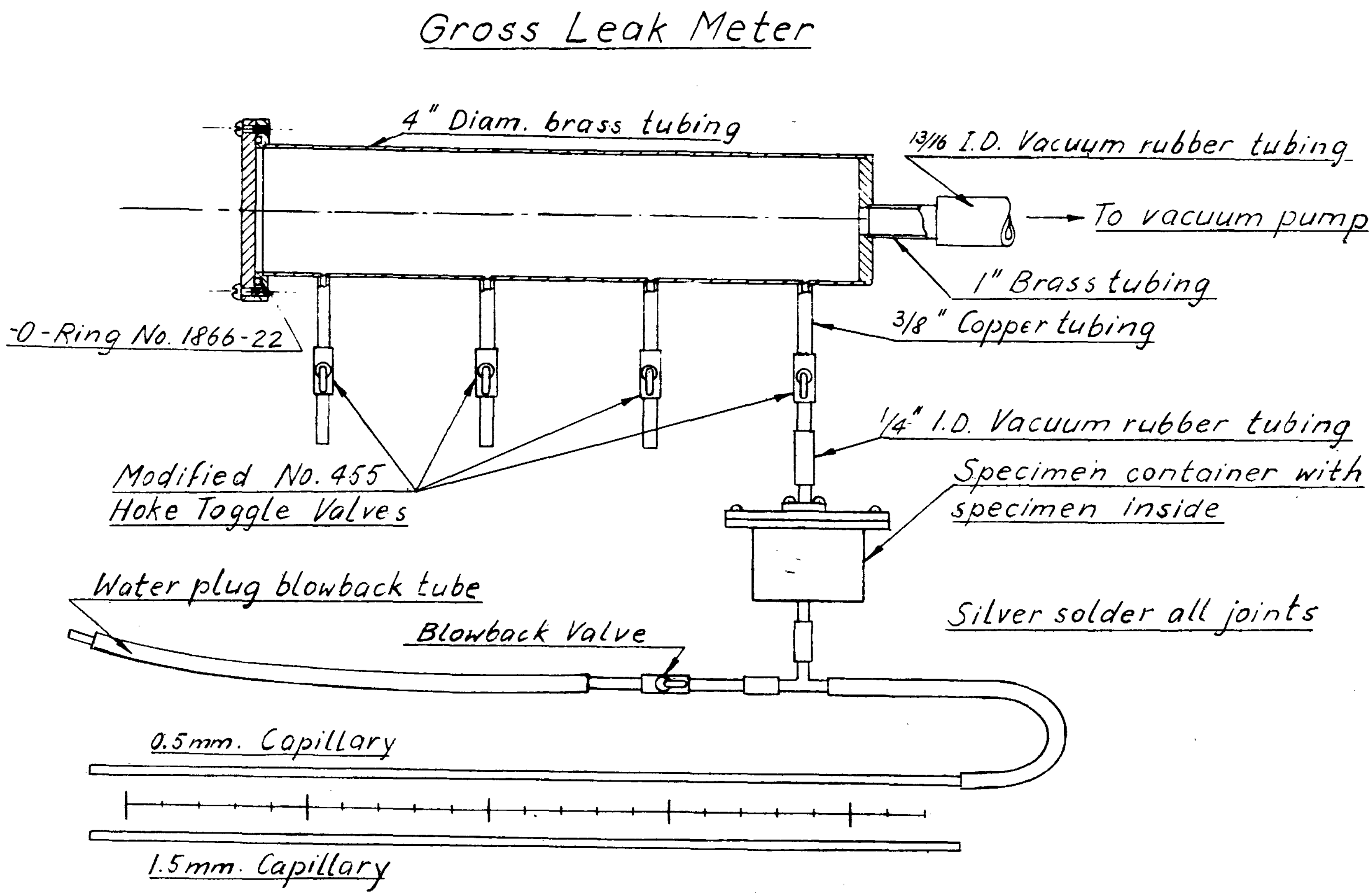


Figure 10. Assembly Drawing.
Gross Leak Meter.

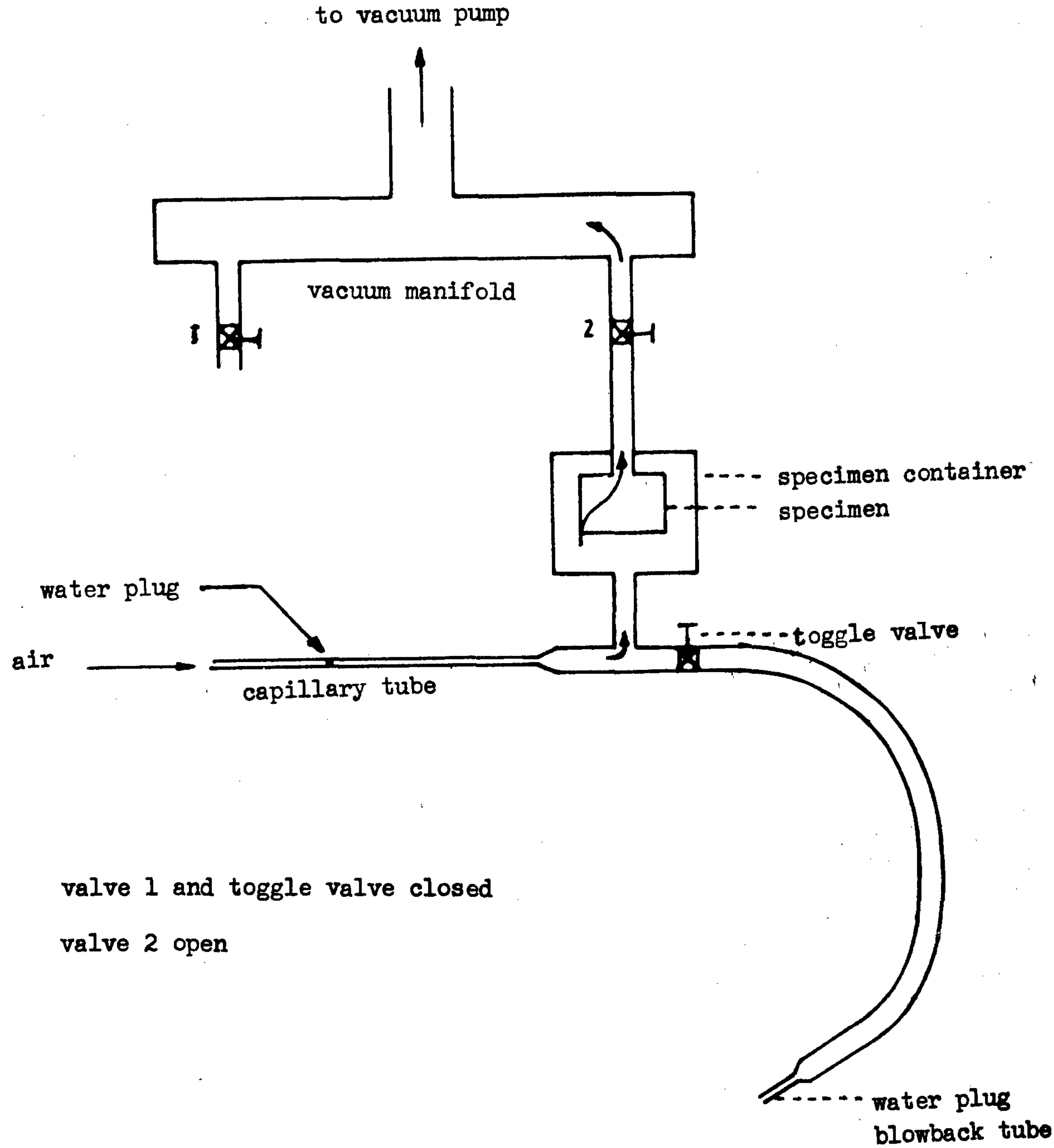


Figure 11. Path of Air Through Gross Leak Meter

3) Hoke Toggle Valves

Four Hoke No. 455 toggle valves were modified to make the valves vacuum tight in both directions. These valves were disassembled, the bodies beveled, and reassembled with an "O" ring inserted on the body of the valve. Details of the modification are shown in Figure 6. Copper tubing, 3/8 inch O. D., is silver soldered into both ends of the valves and one end of each silver soldered to the manifold. Only one manifold valve is used at a time, the other three being incorporated into the design in case several specimens were to be measured simultaneously.

The blowback valve closes off the blowback tube during the measurement when all air must pass through the calibrated capillary. It is opened at the end of the run to stop the movement of the water plug and allows the water plug to be returned to the starting point. This Hoke No. 455 toggle valve need not be modified if the vacuum tight side is placed facing the specimen container and capillary tube.

4) Specimen Container

The specimen container is identical to that used with the High Sensitivity Leak Meter and shown in Figure 7. It likewise provides proper pressure boundary conditions and can be used to measure both in- and out-leakage. The only difference is that the pressure is one atmosphere of air rather than one atmosphere of hydrogen.

If in-leakage is to be measured, air at one atmosphere surrounds the specimen in the specimen container. In this case, the inside of the specimen is evaluated by connecting the specimen tube to the manifold toggle valve. If there is a leak in the specimen, air can pass through into the inside of the specimen, causing movement of the water plug.

If out-leakage is to be measured, the specimen container with the specimen inside is turned over, reversing the air and vacuum leads. In this case, the outside of the specimen is evacuated by connecting the specimen container tube to the vacuum manifold toggle valve. The inside of the specimen then contains air at one atmosphere, connected directly to the capillary tube. If there is a leak in the specimen, air passes through to the outside of the specimen, causing movement of the water plug.

The specimen container was designed as a vacuum tight enclosure for the specimens. Wing screws and flanges are provided for quick assembly and disassembly of the container; "O" rings are used to seal the specimen container at the cover and around the specimen tube. The T section below the specimen container is fabricated from 3/8 inch copper tubing.

5) Capillary Tubes

Glass capillary tubes provide a direct, quantitative measure of the leakage rate since the time required for a small water plug to move a given distance is recorded. With the cross sectional area of the capillary bore known, the volume swept out by the water plug during this time can be computed and the leakage rate determined. Trubore glass capillary is used because of the uniformity of the bore. The 1.5 mm. glass capillary was used to measure leakage rates from 50,000 to 3,000,000 std. cc of air/year. The 0.5 mm. glass capillary can be used for measuring the smaller leakage rates, from 15,000 to 50,000 std. cc of air/year. The capillaries are sealed off in convenient units for computing leakage rates and a stop watch was used for timing the water plug.

The upper limit on leakage rate measurement occurred when the water plug moved so fast that timing was difficult. The lower limit on leakage rate measurement was determined by the accuracy desired and errors introduced by the resistive and inertial forces affecting the movement of the water plug. As the rate of water plug movement decreases, these errors increase causing the leakage rate measurements to become more inconsistent.

The errors due to starting inertia were minimized by:

a) Using a water plug instead of mercury.
b) Using a water plug of minimum length, about 1 mm. long.
c) Timing the water plug movement only after it reached a constant velocity.

The error due to the resistive forces of surface tension was minimized by coating the inside of the cleaned capillary tubing with G.E. Dri-film 9987, an organosilicon compound. This was very effective in preventing the water from wetting the glass.

6) Water Plug Blow Back Tube

The water plug blow back tube was used to return the water plug to its starting point after completion of a run. While the plug can be blown back to the starting point by the operator, greater control of the plug movement can be obtained by closing off the end and squeezing the tubing. Vacuum rubber tubing, 1/4 inch I. D., was used for all connections.

SECTION IV

CALIBRATION OF THE BINARY LEAK METER

A. General

Calibrated leaks were used to calibrate the complete range of the High Sensitivity Leak Meter and the 0.5 millimeter capillary of the Gross Leak Meter. The larger calibrated leaks were purchased from the Vacuum Electronic Engineering Corporation while the smaller leaks were obtained from the General Electric Company. The larger leaks had been calibrated for helium leakage while the smaller leaks had been calibrated for air leakage.

A discussion of the flow of gases through the types of leaks being investigated is warranted because the leakage rate depends on the gas used and the type of flow assumed. In addition, correlation is to be established between the leakage rates shown by the test method using hydrogen, and leakage to air, oxygen, and water vapor.

B. Analysis of Gas Flow

To convert from leakage rates with one gas to leakage rates for another gas through the same calibrated leak, it is first necessary to decide what laws of flow govern the leakage rate. The leakage could be viscous flow, which is governed by the Poiseuille Law, molecular flow, or a combination of these, called intermediate flow. Dushman has an excellent treatment of flow in Chapter 2, Scientific Foundations of Vacuum Technique.

In order to calculate the type of flow through the calibrated leaks, the radius of the hole must first be known. Since the leaks were made by pinching off tubing, the radius is completely undetermined. The flow region is likewise indeterminate. Viscous flow tends to predominate in larger leaks while molecular flow occurs more in smaller leaks. There is also a pressure dependence, the flow going from viscous to molecular as the pressure is reduced.

Several tests were conducted to determine experimentally the viscous and molecular flow regions since they could not be calculated.

The following tests show that two calibrated leaks measured on the Gross Leak Meter were completely in the viscous flow region.

Two calibrated leaks of known leakage rate for helium were measured to evaluate their air leakage rates on the Gross Leak Meter. The air leakage rate was also computed from the known helium leakage rates assuming viscous flow in one case and molecular flow in the other.

The method of computation was as follows:

The leakage rates, expressed in micron cu. ft./hr. by the manufacturer, were converted to std. cc./yr. by multiplying by 329 as shown in the following Leakage Rate Conversion Table. Thus, Calibrated Leak No. 377 had a leakage rate of 662,000 std. cc. of helium/yr. while Calibrated Leak No. 378 had a leakage rate of 66,100 std. cc. of helium/yr.

Leakage Rate Conversion Table

1 micron liter/sec.	$= 1.32 \times 10^{-3}$ std. cc./sec.
	$= 4.17 \times 10^{4}$ std. cc./yr.
	= 127 micron ft.^{3}/hr.
1 micron ft.^{3}/hr.	$= 1.04 \times 10^{-5}$ std. cc./sec.
	= 329 std. cc./yr.
	$= 7.88 \times 10^{-3}$ micron liters/sec.
1 std. cc./sec.	$= 3.16 \times 10^{7}$ std. cc./yr.
	= 760 micron liters/sec.
	$= 9.62 \times 10^{4}$ micron ft.^{3}/hr.

Assuming viscous flow,

$$Q = \frac{K(P_2^{\ 2} - P_1^{\ 2})}{n} \qquad (1)$$

Where Q is the leakage rate
K is the same constant for any one leak
P_2, P_1 are the pressures on opposite sides of the leak.
n is the coefficient of viscosity of the gas at the temperature of the gas

If the leakage rates of helium and air are measured through the same leak, keeping all other factors constant,

$$Q_{air} = \frac{n_{He}}{n_{air}} Q_{He}$$

$$\frac{n_{He}}{n_{air}} = 1.06 \text{ at } 25°C.$$

$Q_{air} = 1.06 \times 662{,}000 = 702{,}000$ std. cc. of air/yr. for Leak No. 377

$Q_{air} = 1.06 \times 66{,}100 = 70{,}100$ std. cc. of air/yr. for Leak No. 378

Now, assuming molecular flow,

$$Q = k\sqrt{\frac{T}{M}}\,(P_2 - P_1) \qquad (2)$$

Where Q is the leakage rate
k is the same constant for any one leak
T is the absolute temperature of the gas
P_2, P_1 are the pressures on opposite sides of the leak
M is the molecular weight of the gas.

If the leakage rates of helium and air are measured through the same leak, keeping all other factors constant,

$$Q_{air} = \sqrt{\frac{M_{He}}{M_{air}}}\, Q_{He}$$

$$\sqrt{\frac{M_{He}}{M_{air}}} = 0.37$$

$Q_{air} = 0.37 \times 662{,}000 = 245{,}000$ std. cc. of air/yr. for Leak No. 377
$Q_{air} = 0.37 \times 66{,}100 = 24{,}500$ std. cc. of air/hr. for Leak No. 378

The following table summarizes the comparison for the different types of flow.

LEAKAGE RATE IN STD. CC. OF AIR/YR.

Calibrated Leak No.	Measured Value	Calculated Values Assuming	
		Viscous Flow	Molecular Flow
377	758,000	702,000	245,000
378	66,400	70,100	24,500

The measured value is 200% greater than the value calculated assuming molecular flow. The measured value differs from the value calculated assuming viscous flow by less than 8%. Therefore, these two leaks are completely in the viscous flow region.

The following tests show that the larger leaks used with the High Sensitivity Leak Meter are also completely in the viscous flow region while the smaller leaks are almost completely in the molecular flow region.

The leakage rate of hydrogen at one atmosphere through four calibrated leaks was measured. The hydrogen pressure was then increased to two atmospheres and the leakage rate through the same calibrated leaks were again measured. The ratio between the leakage rates at the two pressures was used to determine the type of flow.

With the hydrogen pressure on one side of the leak at one atmosphere and the other side connected to the vacuum manifold, $P_2=1$ and $P_1=0$. When the hydrogen pressure was increased to two atmospheres, $P_2=2$ and $P_1=0$. All other factors were kept constant when the pressure was increased.

With $P_1=0$ at all times, it was apparent from equation (1) that the leakage rate Q was proportional to P_2^2 in the case of viscous flow. From equation (2) it was equally obvious that the leakage rate Q was directly proportional to P_2 in the case of molecular flow. Therefore, if the flow was completely viscous, one would expect the leakage rate to increase by a factor of 4 when P_2 is doubled. Likewise, for molecular flow, one would expect the leakage rate to increase only by a factor of 2 when P_2 was increased from one atmosphere to two atmospheres. Intermediate flow, a mixture of molecular and viscous flow, occurs when the ratio of leakage rates is between 2 and 4.

The following table summarizes the results of the leakage rate measurements made with 4 different calibrated leaks at 1 and 2 atmospheres of hydrogen pressure.

LEAKAGE RATE IN STD. CC. OF AIR/YR.

Calibrated Leak No.	Leakage Rate Q_1 at 1 atm. of H_2	Leakage Rate Q_2 at 2 atm. of H_2	$\frac{Q_2}{Q_1}$
378	54,000	250,000	4.6
378	61,000	280,000	4.6
797	22,000	80,000	3.6
797	28,000	82,000	2.9
C129	1,200	4,000	3.3
C129	1,240	4,100	3.3
635	310	670	2.2
635	300	670	2.2

The results show a gradual change from viscous flow through Leak No. 378 to molecular flow through Leak No. 635. Thus, leakage rates above 50,000 std. cc. of air/hr. are in the viscous flow region while leaks smaller than 300 std. cc. of air/yr. are almost completely in the molecular flow region. A mixture of viscous and molecular flow occurs between 300 and 50,000 std. cc. of air/yr. It should be emphasized that these leakage rates define the limits of the flow regions only when the boundary conditions are the same as in the measurements, i.e., a vacuum of the order of a few microns on one side of the leak and a pressure of the order of one atmosphere on the other side.

Molecular flow cannot occur at pressures where the flow is limited by collisions between molecules, i.e., at pressures where the mean free path is short compared to the physical dimensions of the leak. It is impossible to have any appreciable amount of molecular flow at pressures above one millimeter of Hg. As long as the pressures on both sides of a seal are above one millimeter, one can expect the flow to be completely viscous even though the leakage rate might be well below 300 std. cc. of air/yr. Since nearly all sealed components will have absolute pressures in excess of one millimeter of Hg. on both sides of the seal, leakage will be by viscous flow.

From the viscous flow equation (1), it can be seen that the leakage rate is inversely proportional to the viscosity of the gas passing through the leak. With all other factors remaining constant, it is possible to correlate the leakage rates of several common gases. The following table lists the viscosities of the specified gases and leakage rates relative to helium.

Gas	Viscosity (in poises at 25°C.)	Relative Leakage Rate
Hydrogen	0.88×10^{-4}	2.2
Helium	1.96×10^{-4}	1.0
Air	1.85×10^{-4}	1.1
Oxygen	2.07×10^{-4}	0.95
Water Vapor	0.99×10^{-4}	2.0

Therefore, for any given leak and given set of pressure conditions, assuming viscous flow, air will leak in 1.1 times faster than helium, hydrogen will leak in 2.2 times faster than helium, etc.

C. Calibration of High Sensitivity Leak Meter

For quantitative leakage rate measurements, leakage versus time measurements must be reproducible. The situation would be intolerable, for example, if a given leak had a leakage rate of 50 std. cc. of air/yr. when

measured on one day and indicated only 5 std. cc. of air/yr. the next day. Any variation in leakage rate should result only from environmental testing of the specimens so that their effects may be properly evaluated. A variation in the leakage rate measurement of the above magnitude might completely mask any change in leakage rate caused by environmental testing. Consequently, leakage rate measurements with the hydrogen ion gauge were repeated using the same calibrated leak to determine the variation of leakage rates that could be expected on duplicate runs.

Variations were found to be caused by the changing sensitivity of the ion gauge. A considerable portion of this project was devoted to finding and minimizing the various factors affecting the sensitivity of the gauge.

1. Factors Affecting Ion Gauge Sensitivity

The sensitivity of the ion gauge is changed by:

a) Oxidation of the palladium window
b) Contamination of the palladium window
c) Insufficient vacuum in the manifold
d) Simultaneous entry of air and hydrogen into the manifold during measurement.

If air is admitted to the ion gauge, the palladium becomes oxidized even if it is cold. Whenever this occurred, two to three hours of running in time was required to obtain reproducible results on duplicate runs. Therefore, even if the leak meter was not in use, the forepumps were operated continuously to prevent air contact with the palladium. During the "run in" period, several runs were made allowing hydrogen to pass through the calibrated leaks, pumping down between successive runs.

To minimize contamination of the palladium, the cold trap was surrounded by liquid nitrogen when the leak meter was being used. When it was not in use, a mixture of dry ice-acetone was sufficient to keep the trap cool. Whenever the trap contained air at one atmosphere, the trap was first surrounded with dry ice-acetone for the first fifteen minutes of pumping. Liquid nitrogen is cold enough to condense liquid oxygen in the trap which might increase the run-in period. After fifteen minutes, liquid nitrogen was used. The switch was made quickly by using two Dewar flasks to prevent the trap from warming up.

The required vacuum was maintained by opening the valve to the ion gauge only after sufficient vacuum was obtained in the manifold as read on the thermocouple gauge.

Simultaneous entry of air and hydrogen into the leak meter during measurement was prevented by having the entire leak meter vacuum tight and by pumping out the air on both sides of the specimen seal prior to the

run. Leaks in the system can be located by probing on the outside of the system with a jet of hydrogen and observing the leak meter response. Rubber dam is convenient for enveloping a large section of the system with hydrogen. These tests for leak tightness of the system should also include the whole inlet side of the forepump. When testing for leaks, neither pump should be allowed to compete with the ion gauge for the hydrogen. Maximum sensitivity was obtained by turning off the pump in the region being tested. Since there was a slight amount of back diffusion of hydrogen from the pump when it was stopped, it was advisable to pump this off with the other pump before proceeding with the test. Vacuum stopcock grease (Dow-Corning Corp.) was used on all rubber tubing connections and "O" rings to prevent air leakage at these points. It was essential that there be no air leakage into the system.

After the air was evacuated on both sides of the specimen seal, hydrogen was introduced on the side away from the vacuum manifold. Hydrogen alone then passed through any leak in the seal, effecting the maximum sensitivity of the ion gauge.

If the air were not pumped out prior to the run, large variations in leakage rate measurements could be expected. The effective sensitivity of the gauge would depend on just how much hydrogen was excluded by the air passing through the leak.

2. Calibration Runs

A typical series of leakage versus time curves is illustrated in Figure 12 for one of the calibrated leaks just after oxidation of the palladium. The sensitivity of the gauge gradually increases from the first run, No. 72, to those runs where reproducibility is obtained, No. 77, 78, and 79. The time interval between the first and last runs is about three hours. By observing the aforementioned precautions, the ion gauge can be retained at its maximum sensitivity and the run-in period eliminated.

Figure 13 is an average leakage versus time curve after the running-in period. These runs were made over several days to check repeatability. The same calibrated leak was used here as when the palladium was in the oxidized condition. Its leakage rate was 1.3×10^{-6} std. cc. of air/sec. or 41 std. cc. of air/yr. The curve is linear showing that the response of the hydrogen gauge is directly proportional to the hydrogen pressure as well. This results because hydrogen is entering the system at a constant rate through the calibrated leak. Because this hydrogen is expanding into a closed system of constant volume, the hydrogen pressure must increase linearly with time. It is a closed system on these timed runs because Valves A and C leading to the forepumps are closed as shown in Figure 3.

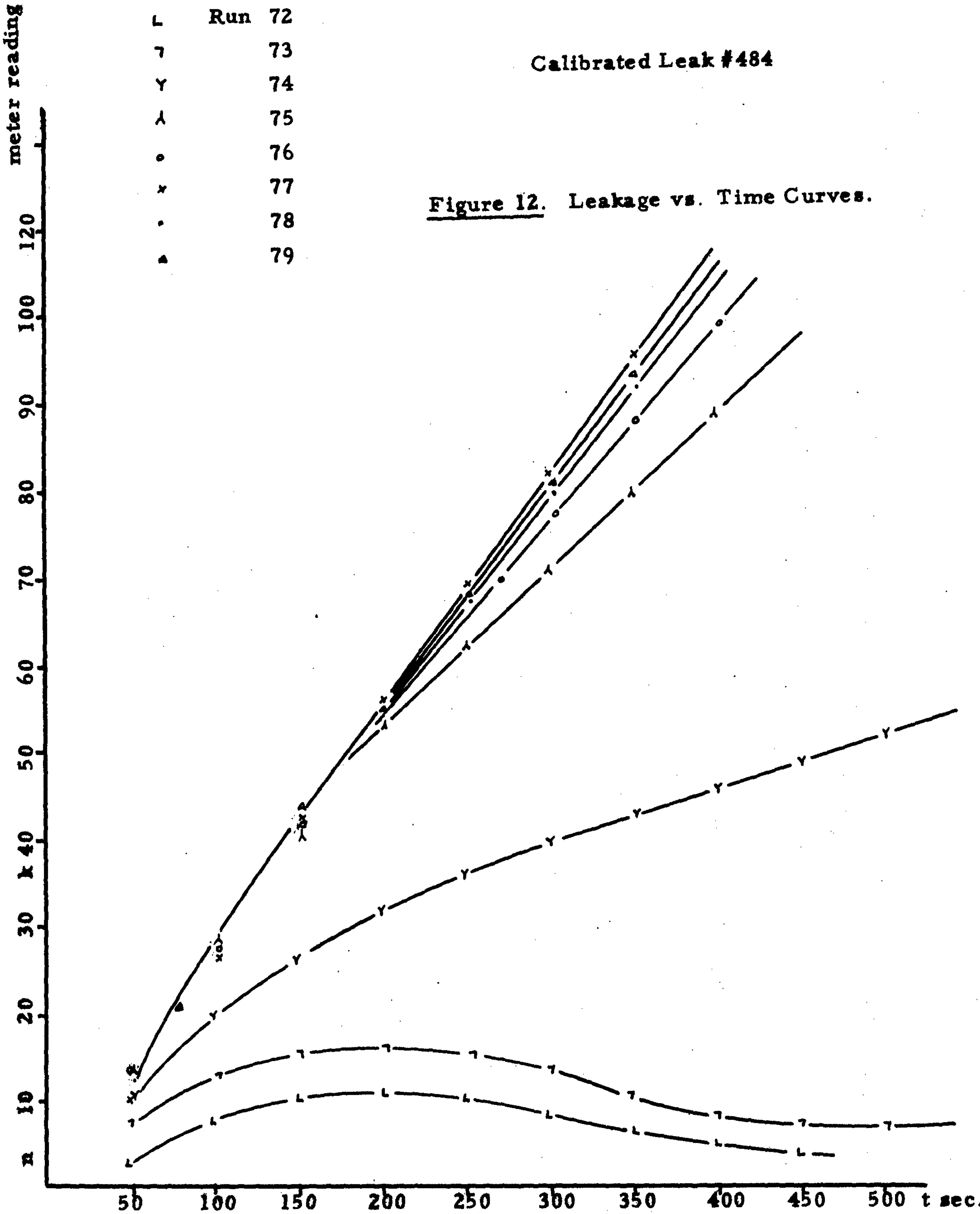


Figure 12. Leakage vs. Time Curves.

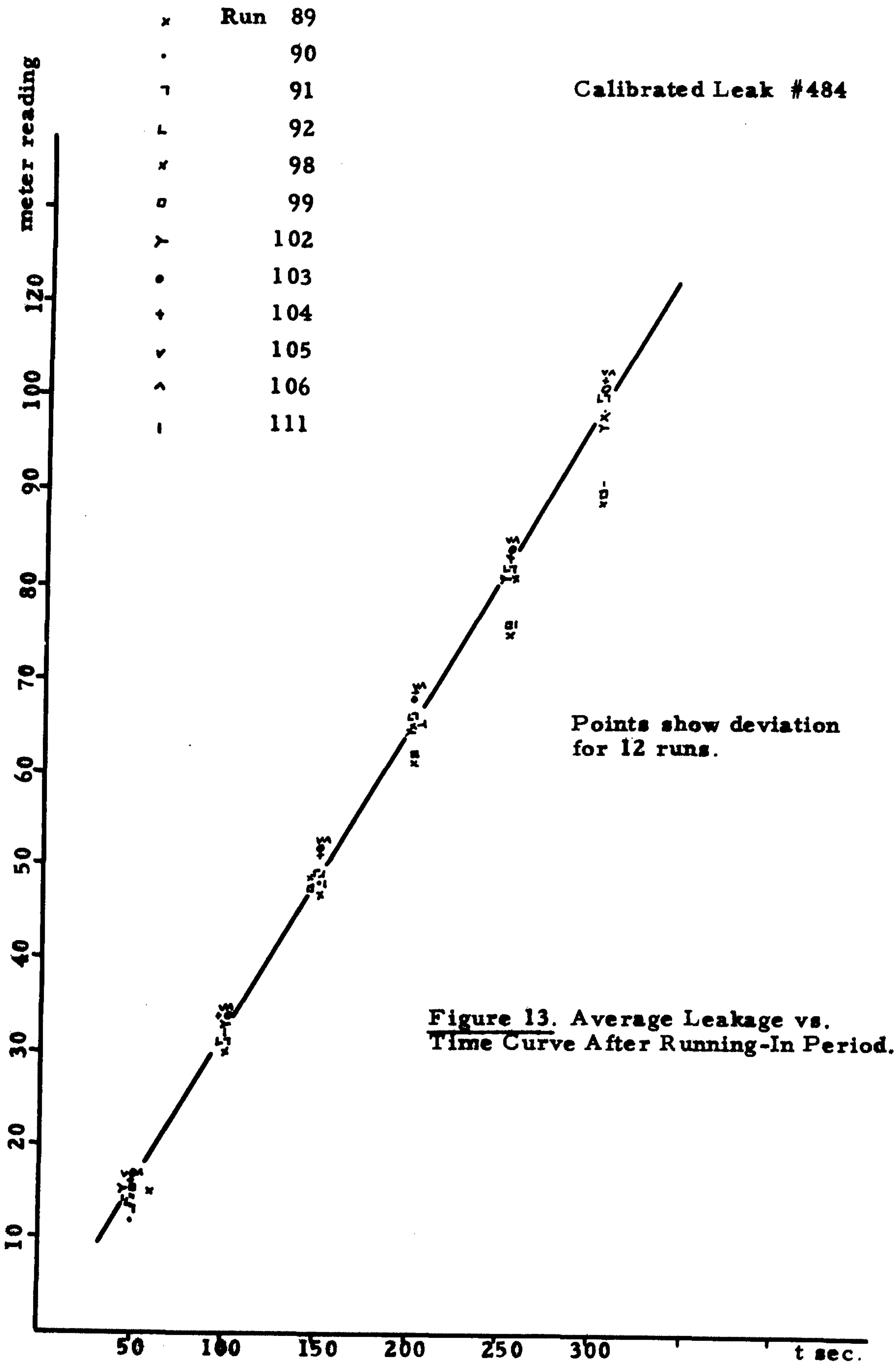


Figure 13. Average Leakage vs. Time Curve After Running-In Period.

Tests were conducted to determine how maximum sensitivity and reproducibility could be maintained. These tests showed conclusively that:

a) Either hydrogen from the hydrogen generator or hydrogen passing through a leak sensitized the ion gauge.
b) The sensitivity of the ion gauge decreased with the time that hydrogen was absent from the hot palladium window of the ion gauge.

These effects were especially noticeable for leaks of the order of 10 std. cc. of air/yr. The sensitivity of the instrument changed little for leaks larger than 500 std. cc. of air/yr.

As a result of the above tests, the following procedure was adopted:

> The ion gauge was given a small shot of hydrogen from the hydrogen generator immediately preceding the run, if no hydrogen had contacted the hot palladium within the previous 20 minutes.

This insured the maximum sensitivity compatible with good reproducibility. The results were very consistent with this procedure.

Another factor causing large variations in leakage rate measurements occurred predominantly in the smaller size leaks. Leaks smaller than 1×10^{-6} std. cc. of air/sec. (32 std. cc. of air/yr.) were particularly susceptible to change because of the extremely small dimensions of the leak. The Consolidated Engineering Corporation of Pasadena, California, describe their experience as follows:

"We attempt to build leaks within a practical, useful range to be used with the Consolidated Leak Detector. Therefore, we do not attempt to build one below the 1×10^{-6} cc./sec. rate. It can be done by decreasing the size of the filter ball that meters the leak of helium. As you have stated, leaks of this magnitude are inconsistent. They are extremely sensitive to moisture and dirt contamination as well as temperature changes."

As might be expected from the above, leaks smaller than 1×10^{-6} std. cc./sec. were extremely difficult to obtain. Of the several manufacturers of vacuum equipment consulted, only General Electric would attempt to make smaller leaks.

Since the calibrated leaks were very susceptible to changing their leakage rates, it was sometimes difficult to determine if non-reproducibility was due to the leak meter or to the calibrated leaks. This difficulty was eliminated by the use of many calibrated leaks. If only one or two of the calibration points changed, the variability could be attributed to the calibrated leaks rather than the leak meter. The probability of all the calibrated leaks changing by the same amount was extremely small.

3. Calibration Curves

Two calibration curves are used for measuring leakage rates from 1 to 100,000 std. cc. of air/yr. The series of Timed Run Calibration Curves for measuring leaks from 1 to 500 std. cc. of air/hr. is shown in Figure 14. The Equilibrium Calibration Curve for measuring leakage rates from 500 to 100,000 std. cc. of air/yr. is shown in Figure 15.

a) Timed Run Calibration Curves

On timed runs, all of the hydrogen entering the vacuum manifold was allowed to go to the hydrogen ion gauge. Valves A and C, leading to both forepumps were closed as shown in Figure 3 to keep them from competing with the ion gauge for the hydrogen. Curves are shown for timed runs of 100, 200, and 300 seconds. Each curve gives directly the leakage rate in std. cc. of air/yr. as a function of increase in leak meter reading during the run. For example, if at the end of 300 seconds, the increase in meter reading was 360, the leakage rate was 400 std. cc. of air/yr. The increase in meter reading was used rather than the absolute meter reading because the meter does not read zero with no hydrogen in the system. Its usual value at the start of the run was about 0.5.

The choice of a 100, 200, or 300 second run was made by the operator. If the meter reading increase was sufficiently high to obtain a good leakage rate determination after 100 seconds, the run was stopped there. If the meter reading increase was not high enough, the run was allowed to continue to 200 seconds. If the reading was still not high enough after 200 seconds, the run was allowed to continue to 300 seconds before recording the meter value and stopping the run. A 300 second timed run was used for the smallest leaks.

The twelve calibration points were obtained using four calibrated leaks having leakage rates of 19, 22, 130, and 470 std. cc. of air/yr. The meter reading increase was plotted for each calibrated leak after 100, 200, and 300 seconds. Three curves are drawn to fit best the points obtained with the three timed runs sets. Three of the points and the origin lie on a straight line for each of the three curves. No explanation is known for the marked deviation of the points obtained with Calibrated Leak No. 635. However, these deviations are consistent and would lie exactly on the curves if its leakage rate were 230 std. cc. of air/yr. instead of the manufacturer's rated value of 130 std. cc. of air/yr.

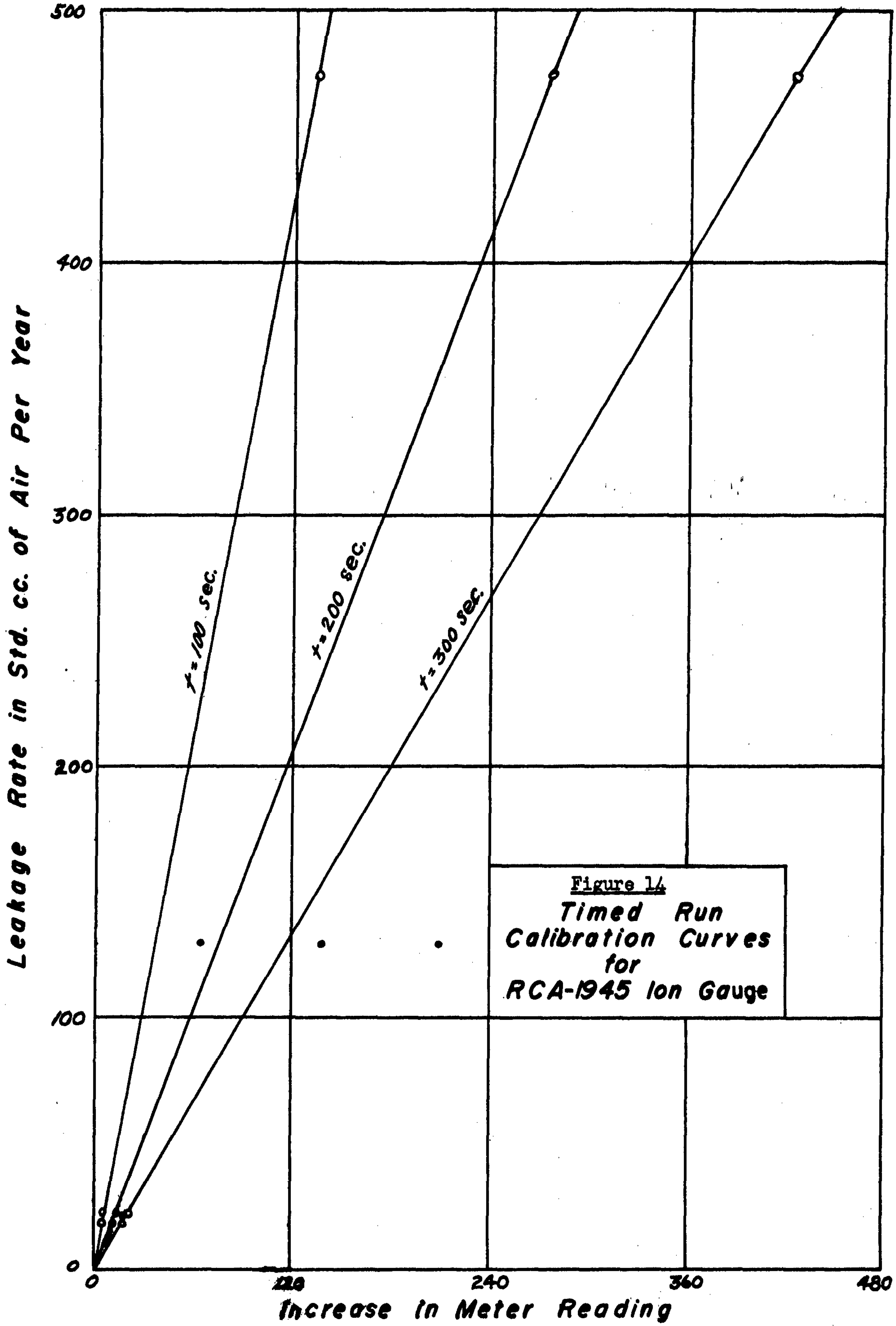


Figure 14
Timed Run
Calibration Curves
for
RCA-1945 Ion Gauge
t=100 sec.
t=200 sec.
t=300 sec.
Leakage Rate in Std. cc. of Air Per Year
Increase in Meter Reading
0
100
200
300
400
500
120
240
360
480

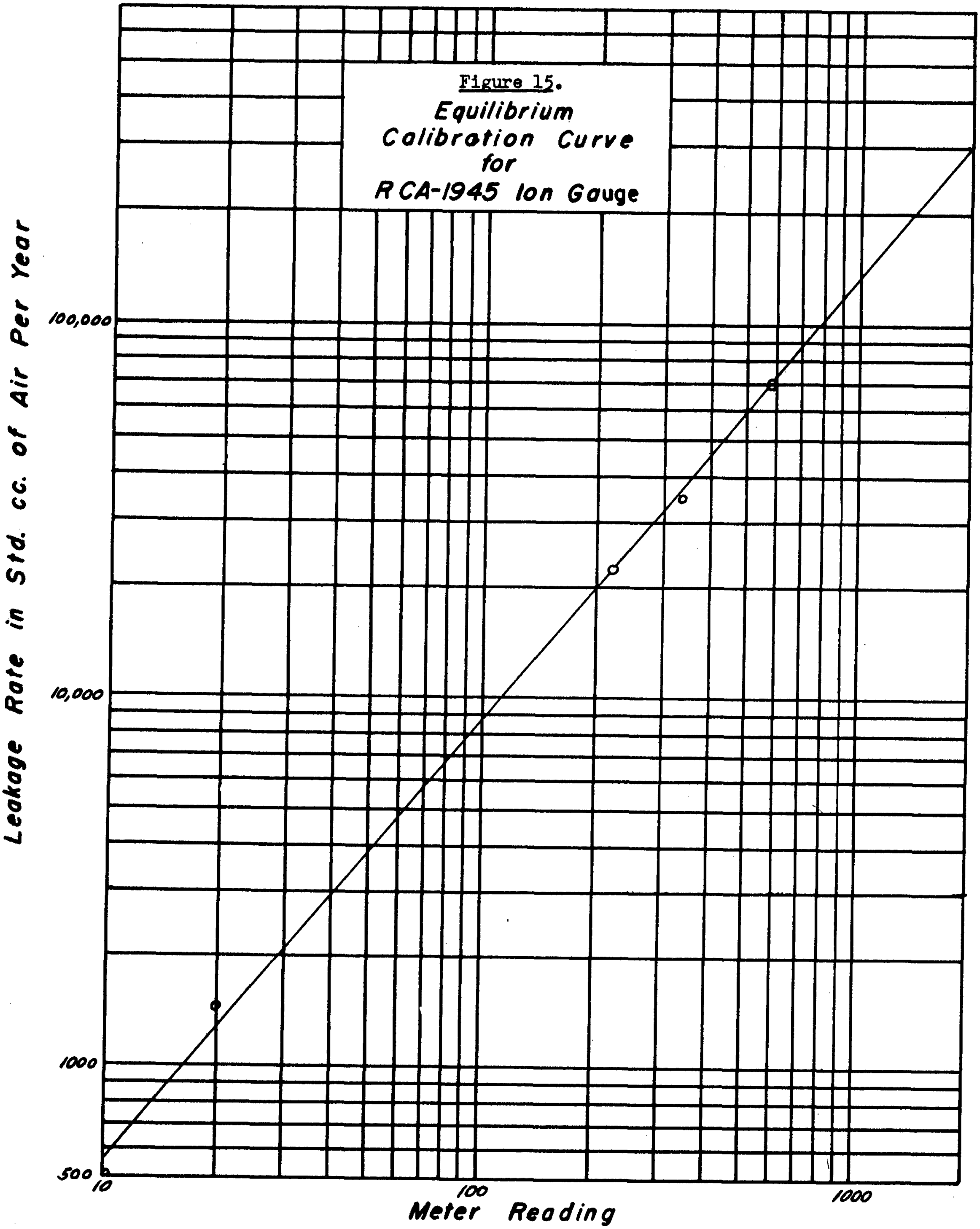


Figure 15.
Equilibrium Calibration Curve for RCA-1945 Ion Gauge
Leakage Rate in Std. cc. of Air Per Year
100,000
10,000
1000
500
10
100
1000
Meter Reading

Each point is an average value of runs made over a period of several weeks to insure reliability. Except for the points obtained with Calibrated Leak 635, the maximum deviation from the average was always less than 20%. Because the curves are linear, the slope of each can be conveniently used for computing the smaller leakage rates more accurately or for extrapolating for larger leakage rates.

b) Equilibrium Calibration Curve

On equilibrium runs, only a small portion of the hydrogen entering the vacuum manifold was allowed to go to the ion gauge. Most of the hydrogen went to the forepump through Valve A which was left wide open as shown for the equilibrium runs in Figure 3. Valve C, leading to the auxiliary forepump, was left closed as in the timed runs.

The five calibration points were obtained using five calibrated leaks having leakage rates of 470, 1450, 22,400, 36,200, and 70,100 std. cc. of air/yr. The value on the leak meter was recorded after equilibrium was reached. Because of the wide range of leaks covered, the equilibrium curve was plotted on a log-log scale.

The leakage rate in std. cc. of air/yr. can be found directly from the curve for a given meter reading. Like the timed run curves, it also shows a linear relationship between leakage rate and meter readings. Each point is an average value of runs made over a period of several weeks. The maximum deviation from the average was always less than 20%.

Equilibrium runs were made when the meter reading increase was too large on the timed runs. For example, if the meter reading reached 200 in less than 100 seconds, Valve A was immediately opened and an equilibrium run made. If it was known in advance that the leakage rate was too large for a timed run, an equilibrium run was made.

D. Calibration of the Gross Leak Meter

Prior to calibration, several coating procedures were investigated to minimize the resistive forces of surface tension on the moving water plug. The following procedure worked satisfactorily and is recommended:

1. Cleaning

Draw a 10% solution of 48% hydrofluoric acid in water into the bore several times with a rubber bulb. Rinse thoroughly with distilled water. Dry by blowing through the capillary (tank hydrogen is satisfactory for this purpose). Polish by passing several strands of sewing thread back and forth through the bore.

2. Coating

Saturate the threads in the bore with G. E. Dri-film 9987 and pull back and forth in the capillary. Dry by blowing through the capillary. Examine visually. If any uncoated spots remain, repeat the process until these disappear. Dry and polish by passing dry threads through the capillary bore.

The water plug is removed from the capillary whenever the Leak Meter is not in use. A distilled water plug about one millimeter long is satisfactory.

3. Calibration Runs

The 1.5 millimeter capillary was calibrated by measurement of its cross sectional area while the 0.5 millimeter capillary was calibrated using a calibrated leak. Calibrated leaks were used to check the validity of the formula used when measuring leaks on the 1.5 millimeter capillary whereas validation and calibration were identical on the 0.5 millimeter capillary.

The cross sectional area of the 1.5 millimeter capillary was determined by measuring the weight and length of a long plug of mercury in the capillary tube, using the expression:

$$A = \frac{M}{LD} \quad \text{where} \quad \begin{aligned} M &= \text{weight of Hg} \\ L &= \text{length of Hg plug} \\ D &= \text{density of Hg.} \end{aligned}$$

The cross sectional area of this capillary was determined as 1.77×10^{-2} cm.^{2}. The leakage rate for this capillary can be calculated from the formula:

$$Q = \frac{Ad}{t} = 1.77 \times 10^{-2} \times \frac{d}{t} \text{ std. cc. of air/sec.}$$

or, converting to std. cc. of air/yr.,

$$Q_{1.5} = 5.59 \times 10^{5} \times \frac{d}{t}$$

Where $Q_{1.5}$ = leakage rate in std. cc. of air/yr.
d = distance in cm. that water plug moves in t sec.
t = time in sec., defined by d.

The validity of the formula for the 1.5 millimeter capillary was checked using two calibrated leaks. Five runs were made with each leak. The measured leakage rate was computed for each run using the above formula and the leakage rates then averaged. (It is incorrect to average the times of the runs, substituting this average time in the formula to compute the average leakage rate.)

LEAKAGE RATES IN STD. CC. OF AIR/YR.

Calibrated Leak No. 377 (leakage rate = 702,000)			Calibrated Leak No. 378 (leakage rate - 70,100)		
t (sec.)	d (cm.)	Measured leakage rate	t (sec.)	d (cm.)	Measured leakage rate
7.1	10	787,000	75.8	10	73,800
6.9	10	810,000	76.1	10	73,400
6.9	10	810,000	77.0	10	72,600
7.2	10	776,000	77.0	10	72,600
7.2	10	776,000	78.6	10	71,100
Average measured leak-rate = 792,000			Average measured leak-age rate = 72,700		

The average measured leakage rates agree with the listed leakage rates within 13% for Leak No. 377 and within 4% for Leak No. 378. The maximum deviation from the average leakage rate is less than 2-1/2% for both leaks.

Ten runs were made on Calibrated Leak No. 797 to determine the average value of k in the formula:

$$Q = \frac{kd}{t}$$

This leak was calibrated for air by the manufacturer and has a leakage rate Q = 22,400 std. cc. of air/yr. With Q known, k can be computed for each run where t and d are measured. These values are listed in the following table.

Calibrated Leak No. 797 Q = 22,400 std. cc. of air/yr.		
t (sec.)	d (cm.)	k
35.9	10	80,420
29.2	10	65,410
31.6	10	70,780
27.6	10	61,820
29.1	10	65,180
29.5	10	66,300
26.4	10	59,140
26.7	10	59,810
29.1	10	65,190
28.1	10	62,940
Average k = 65,700		

Thus, leakage rates measured on the 0.5 millimeter capillary of the Gross Leak Meter can be calculated from the formula:

$$Q_{0.5} = 6.57 \times 10^4 \times \frac{d}{t}$$

Where $Q_{0.5}$ = leakage rate in std. cc. of air/yr.
d = distance in cm. that water plug moves in t sec.
t = time in sec., defined by d.

The maximum deviation of k from the average is about 22%, representing the same deviation in leakage rate when the average value of k is used.

SECTION V

PORTABLE LEAK METER

A. Design

The Gross Leak Meter, originally designed for laboratory measurements, was redesigned for the quantitative measurement of leakage rates on the production line. This portable version of the Gross Leak Meter has been designated as the Portable Leak Meter. Like its prototype, it also measures leakage rates from 15,000 to 3,000,000 std. cc. of air/yr. Thus, the quantitative measurement of leakage rates through sealed components on the production line is possible within these limits.

The Portable Leak Meter is shown in Figure 16. Panels of 1/4 inch plywood are mounted on the welded angle iron framework illustrated in Figure 17. The doors open to a 58 liter/minute Welch 1405B forepump and the pump switch mounted nearby. Before starting the motor, the pulley should be turned a few times in the direction of the arrow to expel oil from the inside of the pump.

Shown in Figure 18 are the side assembly view and drawings of the pump shock absorber retainers, table top, Hoke toggle valve modification, and vacuum system flange details. Figure 19 includes drawings of the adjustable sample table, capillary panel detail and vacuum system assembly.

The shock absorber retainers preserve shock absorbing properties, yet prevent the pump from sliding when the leak meter is moved up inclines. The 3/4 inch ply wood table top sets rigidly in the upturned angle iron framework. An all metal vacuum system was used because of its sturdiness and ease of disassembly for cleaning and maintenance. All three "O" ring flanges were made identical for economy in fabrication and "O" ring stocking. Two Hoke toggle valves extend downward from the vacuum manifold behind the capillary panel. Both valves were modified to make them completely vacuum tight. The capillary panel is positioned at average eye level and is rotatable about its long axis so that it can be oriented perpendicularly to the line of sight of observers of different height. Two glass capillary tubes, approximately 1.5 mm. I.D. and 0.5 mm. I. D. are mounted flush with the opal glass panel and illuminated from behind by a fluorescent light. A scale is marked directly on the opal glass pane. A blowback tube is provided for repositioning the plug at the end of the run. The blowback valve is closed only during the run. This valve need not be modified if the vacuum tight side is placed facing the glass capillary and specimen container. A T section of 3/8 inch copper tubing provides the connection between the specimen container, capillary tubes and the blowback toggle valve. Vacuum rubber tubing, 1/4 inch I.D., is used for all connections. To prevent leakage, vacuum stopcock grease was used at all joints. The capillary treatment and the path of air through the Portable Leak Meter are identical to that for the Gross Leak Meter (Figure 11).

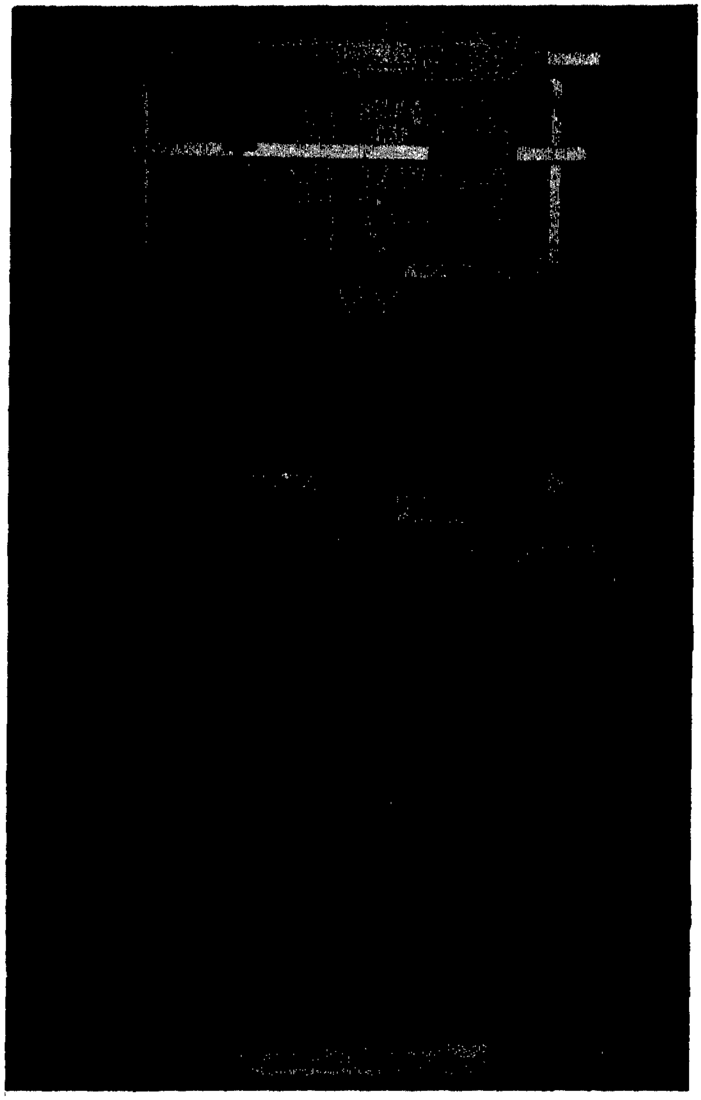


Figure 16. The Portable Leak Meter.

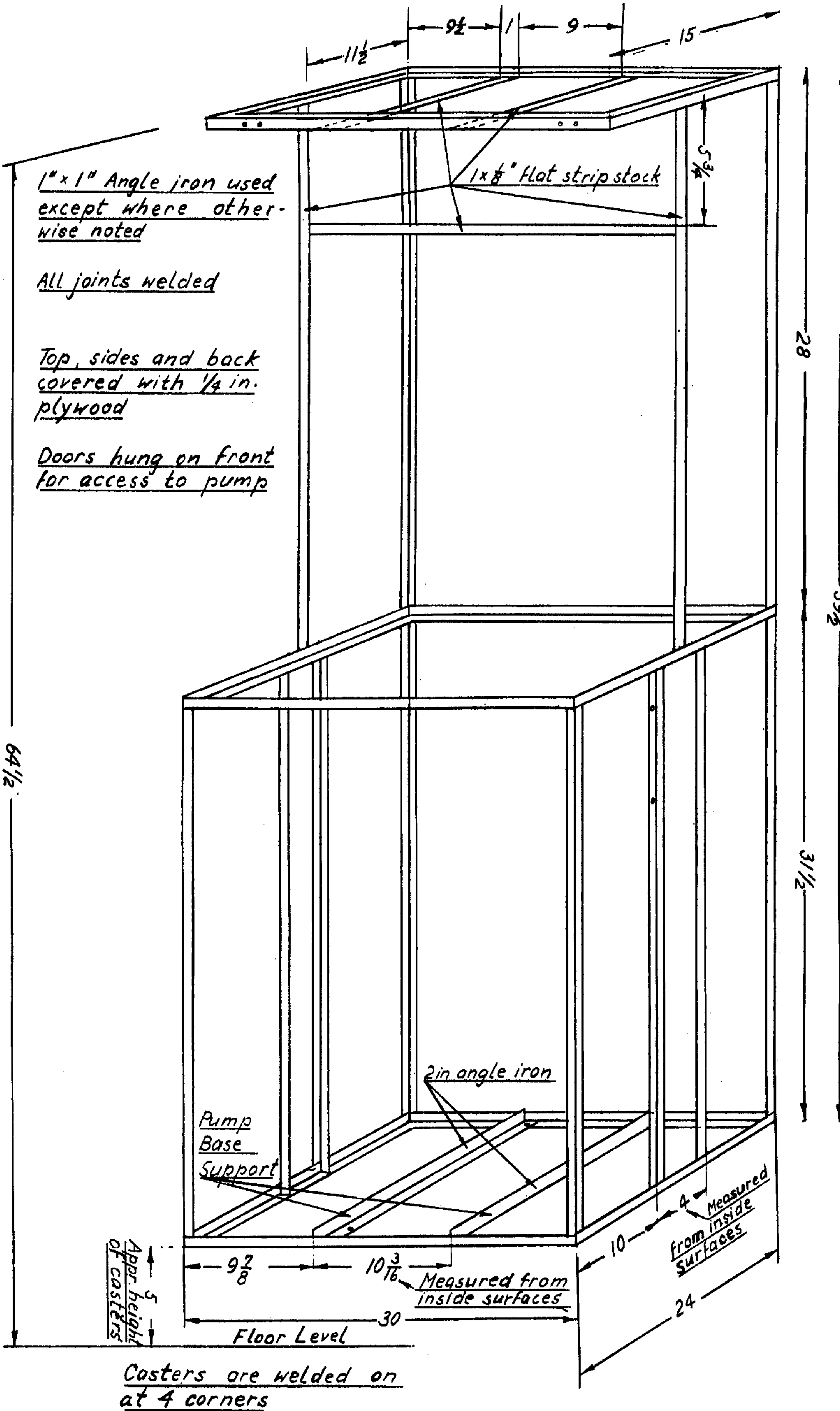


Figure 17. Portable Leak Meter Frame

Figure 18. Side Assembly and Auxiliary Parts of Portable Leak Meter

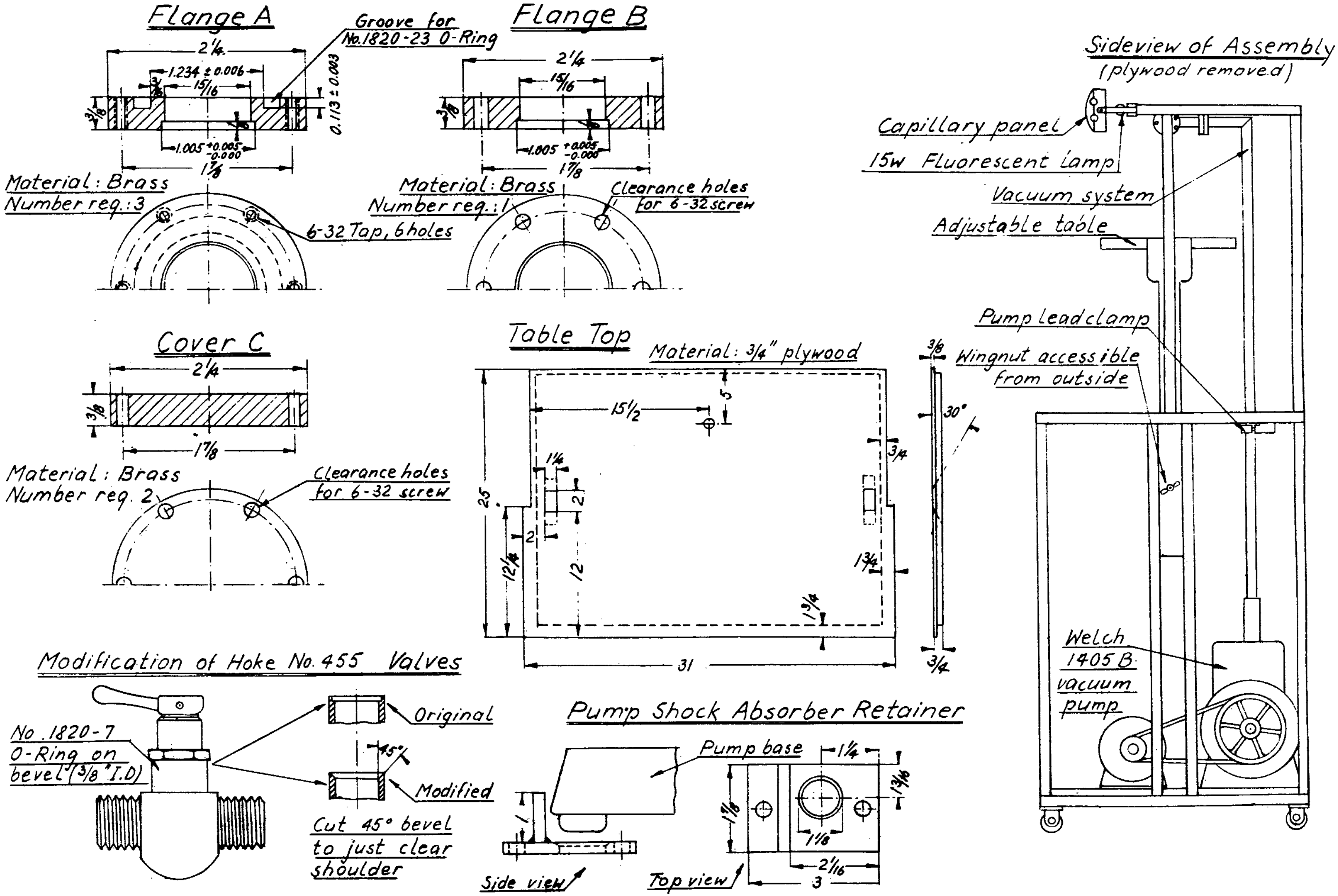
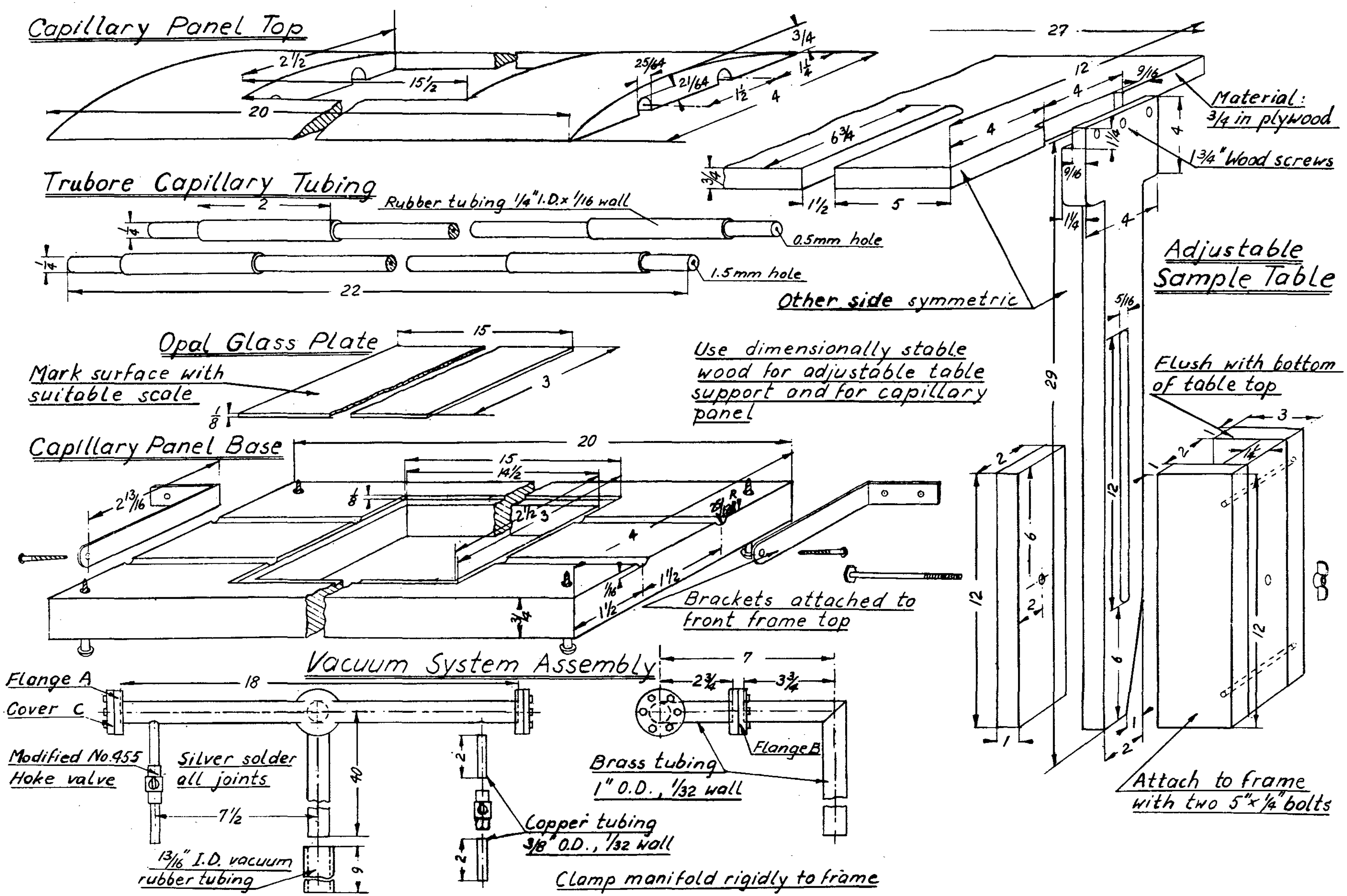


Figure 19. Sample Table, Capillary Panel and Vacuum System Assembly - Portable Leak Meter



To minimize pump down time the specimen container should not be excessively larger than the specimen. The medium sized specimen container shown in Figure 8 can be used for all specimens smaller than 2-3/4 inches diameter x 2 inches long. The specimen container shown in Figure 20 can be used for larger specimens, smaller than 3-3/4 inches diameter x 4 inches long. For considerably larger specimens, the specimen container shown in Figure 21 was constructed. It can accommodate specimens 12-1/2 inches in diameter x 11-1/2 inches long. It should be noted that specimen components of this size must be able to withstand 1500 to 2000 lbs. across the face due to the atmosphere differential during evacuation. Both the specimen tube and container tube emerge from the lid so it will not be necessary to invert the heavy specimen container. Handles were provided to minimize the possibility of scratching the "O" ring surface.

B. Calibration

The procedure for calibration of the Portable Leak Meter was identical to that used in calibrating the Gross Leak Meter. The 1.5 millimeter capillary was calibrated by measurement of its cross sectional area while the 0.5 millimeter capillary was calibrated using a calibrated leak.

The cross sectional area of the 1.5 mm. capillary was determined by the mercury plug method to be 1.80×10^{-2} cm.^{2}. Thus, the leakage rate for this capillary can be computed from the formula:

$$Q = \frac{Ad}{t} = 1.80 \times 10^{-2} \times \frac{d}{t} \text{ std. cc. of air/sec.}$$

or, converting to std. cc. of air/yr.

$$Q_{1.5} = 5.69 \times 10^{5} \times \frac{d}{t}$$

Where $Q_{1.5}$ = leakage rate in std. cc. of air/yr.

d = distance in cm. that water plug moves in t sec.

t = time in sec., defined by d.

The validity of the above formula was checked using two calibrated leaks. Five runs were made with each leak. The measured leakage rate was computed using the above formula with the d and t of each run and the leakage rates then averaged.

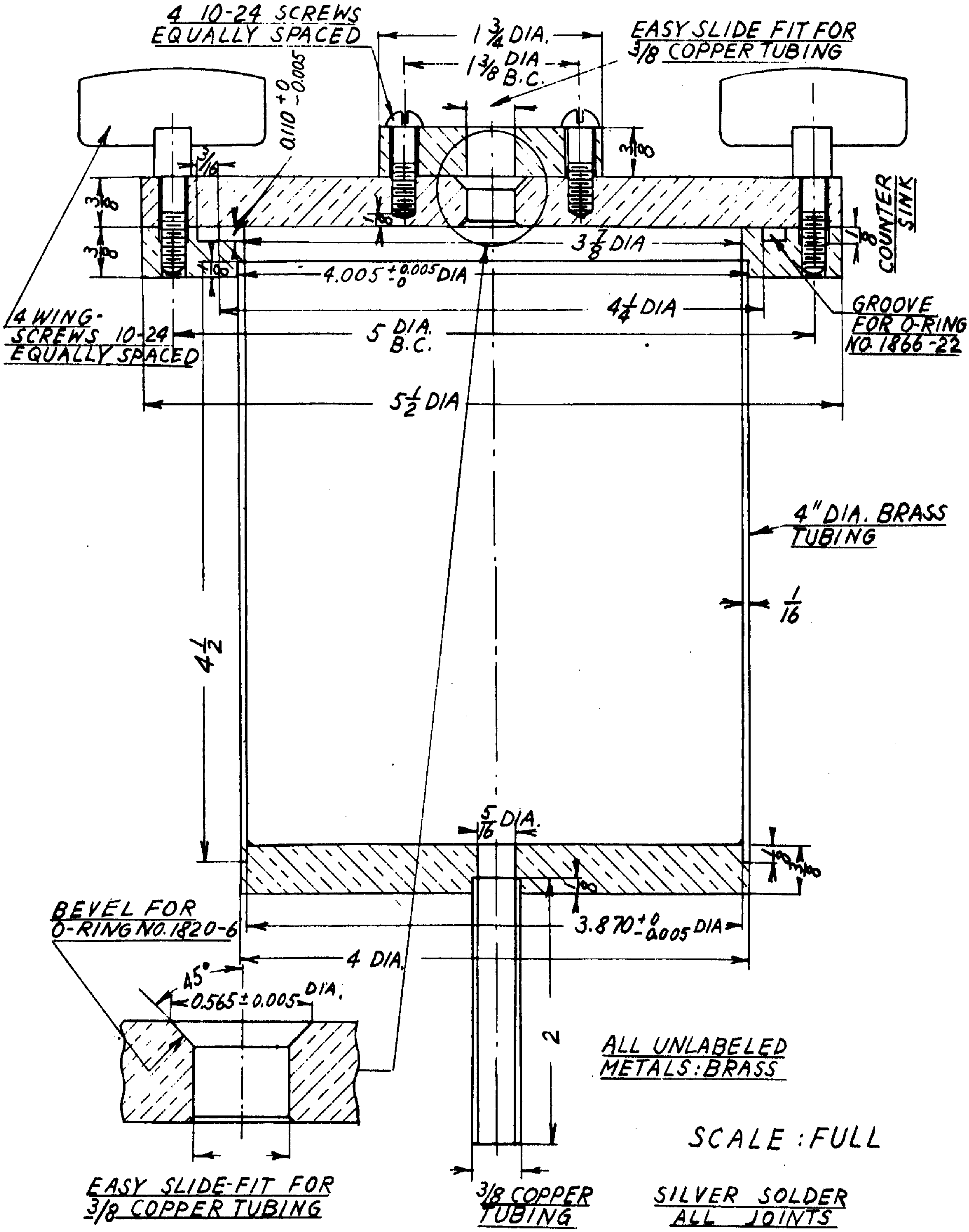


Figure 20. Assembly Drawing of Specimen Container

Figure 21. Large Specimen Container.

LEAKAGE RATES IN STD. CC. OF AIR/YR.

Calibrated Leak No. 377 (leakage rate = 702,000)			Calibrated Leak No. 378 (leakage rate = 70,100)		
t (sec.)	d (cm.)	Measured Leakage rate	t (sec.)	d(cm.)	Measured Leakage rate
7.2	10	790,000	72.2	10	78,800
7.4	10	769,000	75.8	10	75,000
7.6	10	749,000	74.3	10	76,600
7.3	10	779,000	77.0	10	73,900
7.3	10	779,000	76.1	10	74,800
Average measured leakage rate = 773,000			Average measured leakage rate = 75,800		

The average measured leakage rates agree with the listed leakage rates within 10% for Leak No. 377 and 8% for Leak No. 378. The maximum deviation from the average leakage rate is less than 4% for both leaks.

The 0.5 millimeter capillary was calibrated as follows:

Ten runs were made with Calibrated Leak No. 797 to determine the average value of k in the formula:

$$Q = \frac{kd}{t}$$

This leak was calibrated for air by the manufacturer and has a leakage rate Q = 22,400 std. cc. of air/yr. With Q known, k can be computed for each run where t and d are measured. The values are listed in the following table:

Calibrated Leak No. 797 $Q = 22{,}400$ std. cc. of air/yr.		
t (sec.)	d (cm.)	k
27.0	10	60,480
27.7	10	62,050
22.0	10	49,280
27.0	10	60,480
27.5	10	61,600
26.7	10	59,810
29.6	10	66,300
31.2	10	69,890
30.9	10	69,220
28.0	10	62,720
Average k = 62,180		

Thus, leakage rates measured on the 0.5 millimeter capillary of the Portable Leak Meter can be calculated from the formula:

$$Q_{0.5} = 6.22 \times 10^4 \times \frac{d}{t}$$

Where $Q_{0.5}$ = leakage rate in std. cc. of air/yr.
d = distance in cm. that water plug moves in t sec.
t = time in sec., defined by d.

The maximum deviation of k from the average is about 21%, representing the same deviation in leakage rate when the average value of k is used.

C. Correlation

A total of 43 sealed electronic components was submitted to this laboratory by Wright Air Development Center for correlation measurements between the Portable and Gross Leak Meters. Only 5 of these components had leakage rates which were measurable on both instruments. Although the other 38 components could not be used for correlation purposes, they were measured on the High Sensitivity Leak Meter wherever possible to provide additional data. Six of the components could not be connected to the latter instrument because they were filled with oil.

The leakage rate correlation data are as follows:

Sample No.	Measured Leakage Rate (in std. cc. of air/yr.)	
	Portable Leak Meter	Gross Leak Meter
20	22,000	20,000
21	14,000	9,000
22	20,000	16,000
30	2,500,000	2,300,000
32	37,000	29,000

Although these components exhibited leakage rates which correlated rather well with both instruments, it is recommended that calibrated leaks be used for correlation rather than components. Calibrated leaks are much less likely to change their leakage rates. On several tests, especially with Samples 26 through 37, the leakage rate would suddenly change during the measurement. The leakage rate values obtained on duplicate runs would at times be completely different.

The complete set of leakage rate measurements of these components may be found in Section X, "Results of Leakage Rate Measurements".

All test and operating procedures listed for the Gross Leak Meter also apply to the Portable Leak Meter.

PART II

LEAKAGE MEASUREMENTS

SECTION VI

TEST SPECIMENS

A. Identification

The test specimens were identified in accordance with the classification and definition given in Exhibit No. MCREE-752 and also with respect to the basic material. Thus, the following designations were used for the different classes of seals:

1. Class A, Fused Seals
   a) Metal to Metal
      AAA - aluminum to aluminum
      AAB - brass to brass
      AAS - steel to steel

   b) Metal to Ceramic
      AB - ceramic to steel
      AB - ceramic to Kovar

2. Class B, Adhesive Seals
   BA - adhesive to aluminum
   BB - adhesive to brass
   BS - adhesive to steel

3. Class C, Gasket Seals
   CA - gasket to aluminum
   CB - gasket to brass
   CS - gasket to steel

4. Class D, Lapped Seals
   DA - aluminum to aluminum
   DB - brass to brass
   DS - steel to steel

Serial numbers following the letter designations further classify the type of seal. Thus, for the Class C (gasket) seals with aluminum bodies and covers, Specimens CA 16 through 25 have a natural rubber gasket while Specimens CA 26 through 35 have a cork-neoprene gasket (Armstrong DC 100). A complete description of each seal may be found below.

B. Details of Fabrication

In conformity with the specifications of Exhibit No. MCREE-752, test specimens were fabricated, insofar as was possible, in the same fashion as cases for hermetically sealed electrical indicating instruments. Of the total of 449 test specimens prepared, 90 were from cases supplied by the

Marion Electrical Instrument Company. The balance were machined from aluminum, brass and steel bar stock with a 1 inch diameter hole, making the under surface of the seal exposed to internal gases at least 3.14 inches long.

The Marion meter cases were Type HM2, fabricated from #1010 cold rolled steel, hot dipped tin coated. The aluminum bodies and covers were fabricated from dead soft aluminum bar stock. The brass bodies and covers were fabricated from free cutting brass rod composed of 62% copper, 35% zinc and 3% lead. The cold rolled steel bodies and covers were fabricated from #C1117 cold rolled steel bar stock. The hot rolled steel bodies and covers were fabricated from #C1018 hot rolled steel bar stock.

For connection to the testing apparatus, copper tubes, 3/8 inch in diameter by 1-7/8 inches long were silver soldered to all brass and steel specimens while aluminum tubes were soldered to the aluminum specimens. Easy Flo 45 was used with Anti-Borax No. 16 as flux for the brass and steel specimens while EutecRod 190 with Eutector Flux No. 190 was used for the aluminum specimens. In order to insure no leaks at the point where the tubing joined the specimen, only those specimens with perfectly smooth solder fillets at these joints were used. For solder fillet geometry of this type, visual inspection is virtually foolproof in determining which joints are leak tight.

All test specimens were inspected visually after fabrication to determine that each was a perfect seal of its kind. The actual sealing surfaces of the Class C gasket type seals and the Class D lapped type seals could, of course, not be inspected after sealing for the seal was not visible then. However, the gasket grooves and mating surfaces were inspected before assembly for nicks and scratches. The lapped surfaces were inspected for minute scratches with a microscope (1000x magnification) before assembly.

The following is a detailed description of the types of seals fabricated and the method of fabrication.

1. <u>Class A - Fused Seals</u>

a) Metal to Metal

AAA 1 through 10
Aluminum bodies and covers were machined from soft aluminum bar stock as shown in Figure 22. EutecRod 190 aluminum solder and Eutector Flux No. 190 were used for the seal. The seal length was 4.3 inches.

AAB 1 through 10

Brass bodies and covers were machined from bar stock as shown in Figure 22. Five have insert covers and five have overhang covers. Easy Flo 45 silver solder and Anti-Borax No. 16 flux were used for the seal. The seal length was 4.3 inches.

AAB 11 through 20

Brass bodies and covers were machined from bar stock as shown in Figure 23. Soft solder, 50-50 grade and Rubyfluid Soldering Flux were used for the seal. The seal length was 4.3 inches.

AAS 1 through 10

Steel bodies and insert type covers were machined from cold rolled bar stock as shown in Figure 22. Easy Flo 45 silver solder and Anti-Borax No. 16 were used for the seal. The seal length was 4.3 inches.

AAS 11 through 20

Steel bodies and overhang type covers were machined from cold rolled bar stock as shown in Figure 22. Easy Flo 45 silver solder and Anti-Borax No. 16 flux were used for the seal. The length of seal was 4.3 inches.

AAS 21 through 30

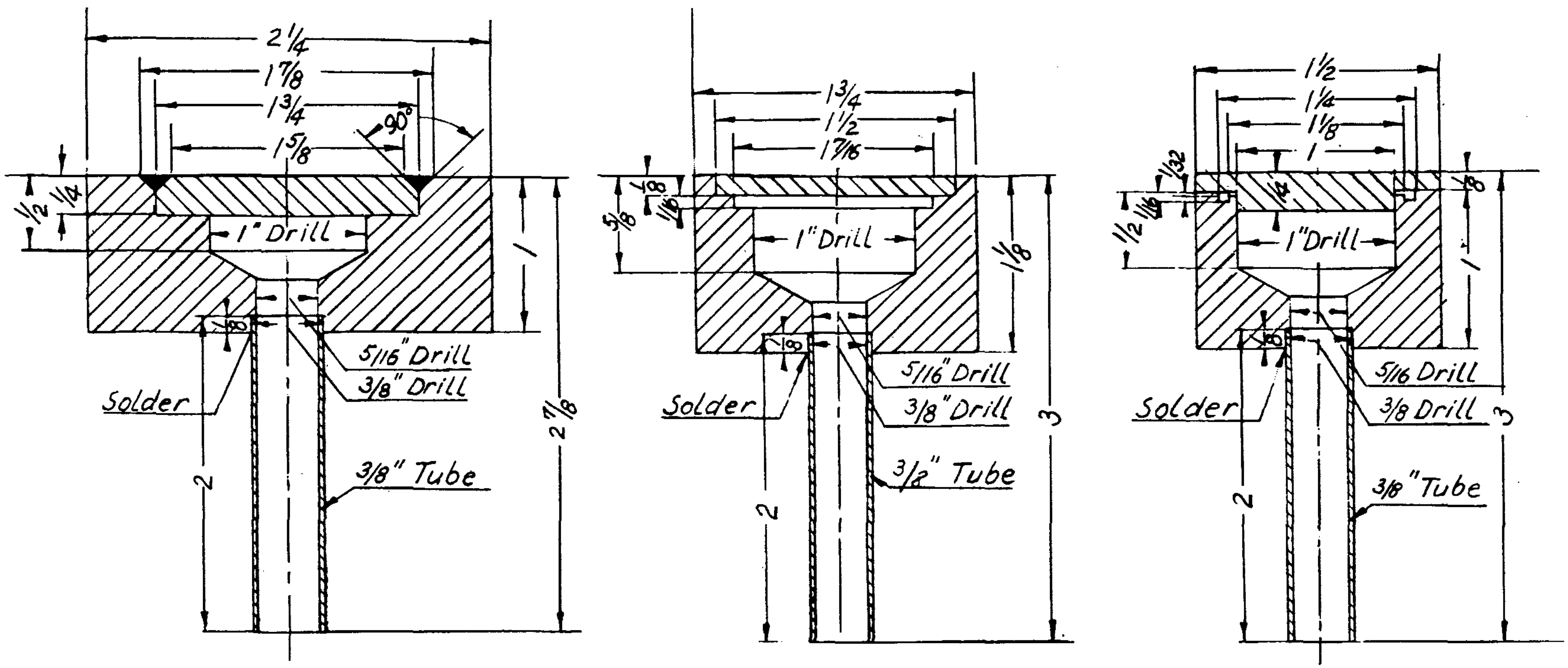
Steel bodies and covers were machined from hot rolled bar stock as shown in Figure 23. An oxy-acetylene torch with welding rod suitable for hot rolled steel was used. The length of seal was 4.7 inches and the welding was done by a commercial welding firm.

AAS 31 through 44

Steel bodies and covers were machined from hot rolled bar stock as shown in Figure 23. An electric arc welder with welding rod suitable for hot rolled steel was used. The length of seal was 4.7 inches and the welding was done by a commercial welding firm.

AAS 45 through 54

A copper tube and a steel disc were silver soldered to the front of the steel Marion meter cases. Three 3/8 inch holes were drilled in the back of the case. As shown in Figure 24, the seal consisted of a steel disc, soft soldered to the back of the case using 50-50 grade solder and Rubyfluid Soldering Flux. The length of seal was 6.3 inches.

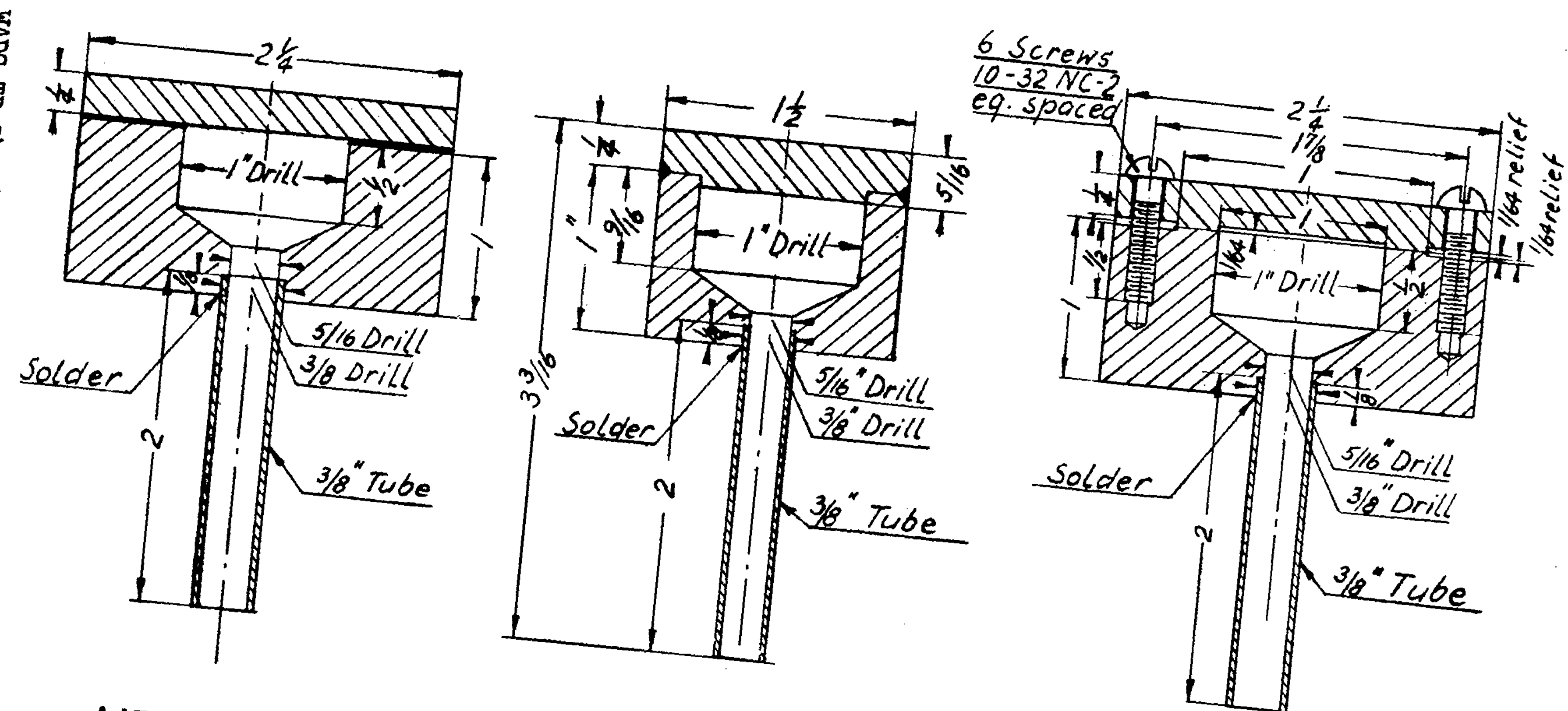


AAA 1-10

AAB 1-10

AAS 1-10 AAS 11-20

Figure 22. Febrication of Fused Seals

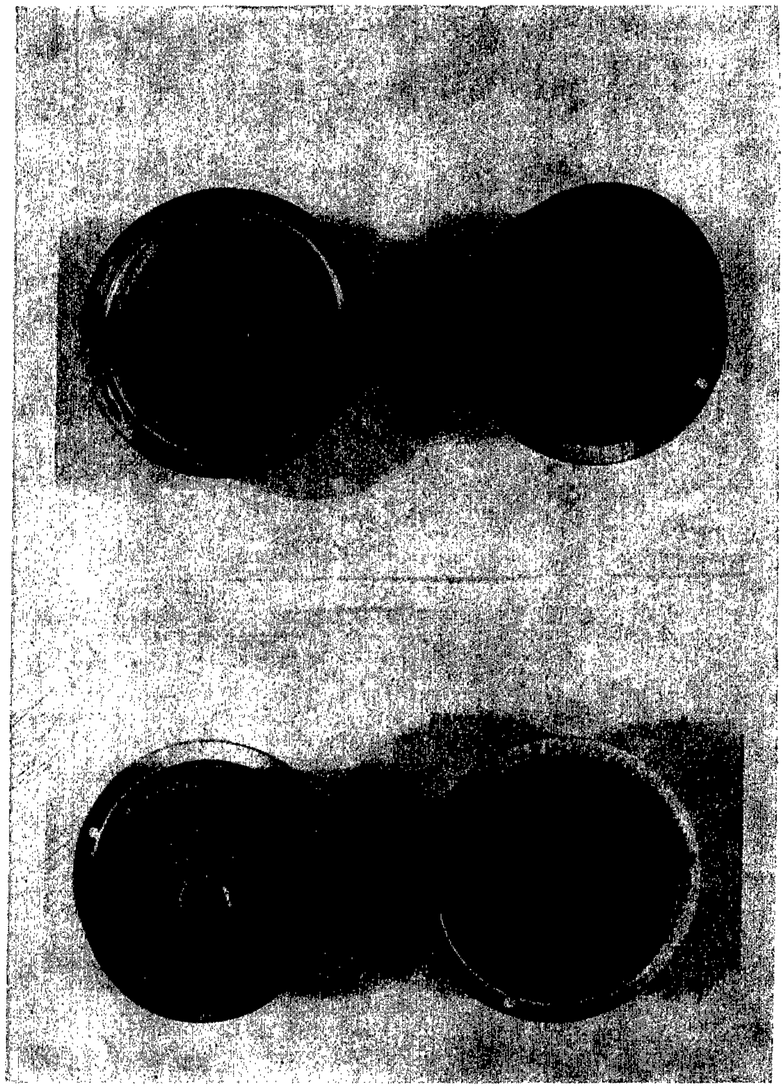


AAB 11-20
BA 1-10
BA 11-20
BA 21-30
BA 31-40
BB 1-10
BB 11-20
BB 21-30
BB 31-40

AAS 21-30
AAS 31-44

DA 1-10
DB 1-10
DS 1-10

Figure 23. Fabrication of Additional Fused Seals and All Lapped Seals.



AAS 45-54
BS 1-10
BS 11-20
BS 21-30
BS 31-40
BS 41-50

BS 51-60

Figure 24. Specimens Employing Marion cases for Soft Solder and Adhesive Steel-to Steel (top) and Neo-Sil-to-Steel (bottom) Seals. The Steel-to Steel seal comprises a steel disc sealed by soft solder or adhesive to the back of the case. In the Neo-Sil-to Steel seal, the front of the case has a Neo-Sil header soft soldered to it.

b) Metal to Ceramic

AB 1 through 10

A copper tube and a steel disc were silver soldered to the front of the steel Marion meter cases. Three Fusite Type #112 FPMC terminals were soft soldered into three 3/8 inch holes in the back of five of the cases. Three Fusite Type #112 MC terminals were soft soldered into three 3/8 inch holes in the back of the other five cases. Soft solder, 50-50 grade, and Rubyfluid Soldering Flux were used, the details being shown in Figure 25. Both types of seals were identical glass to steel seals except for the shape of the soldering terminal outside the seal. The total length of seal was 4.1 inches.

AB 11 through 20

A copper tube and a steel disc were silver soldered to the front of the steel Marion meter cases. Two Electrical Industries Type #E-80W-PP-HV glass to Kovar terminals were soft soldered into two 3/8" holes in the back of the meter case using 50-50 grade solder and Rubyfluid Soldering Flux. The details are shown in Figure 25. The total length of seal was 3.5 inches.

2. Class B - Adhesive Seals

BA 1 through 10

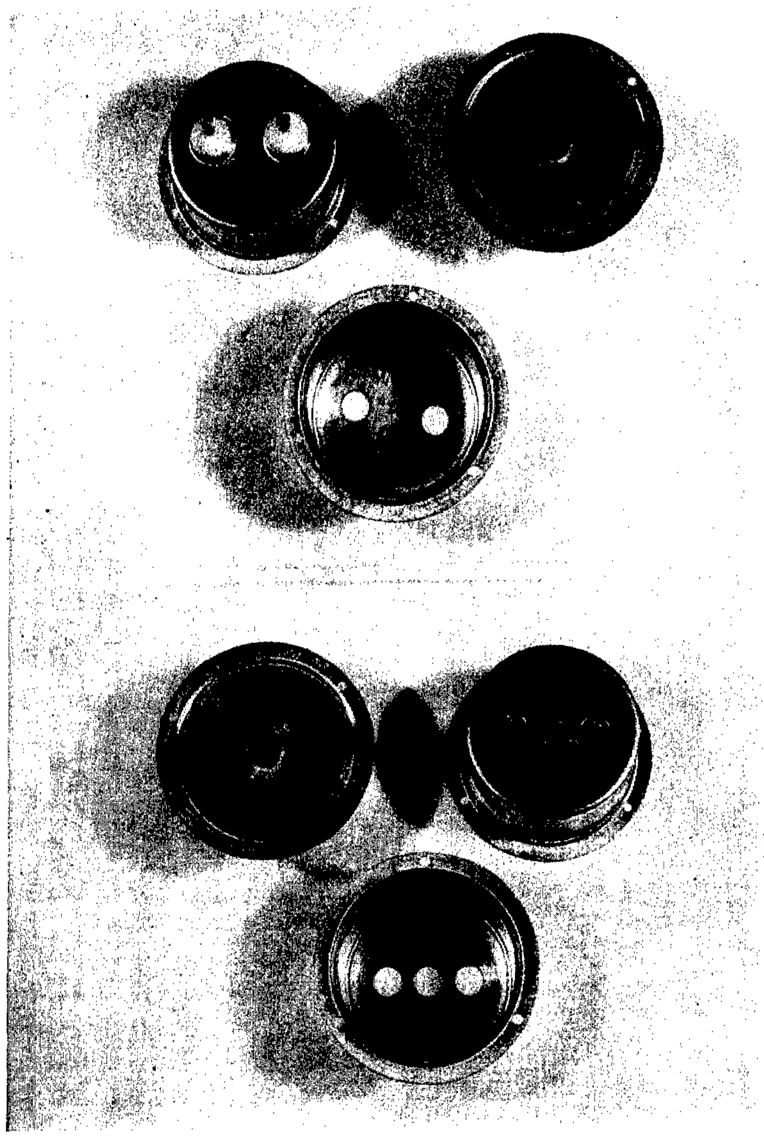
Aluminum bodies and covers were machined from bar stock as shown in Figure 23. Kel F film, Type B, 0.005 inches thick, was clamped between the cover and body and made plastic by heating for 1 hour between 225°C. - 240°C. The length of seal was 3.5 inches.

BA 11 through 20

Aluminum bodies and covers were machined from bar stock as shown in Figure 23. Nitro-Seal was applied between the cover and body which were clamped and retained at room temperature. The seal length was 3.5 inches.

BA 21 through 30

Aluminum bodies and covers were machined from bar stock as shown in Figure 23. Selectron 5208, a polyester, was applied between the cover and body, clamped and cured for 1 hour at 125°C. The seal length was 3.5 inches.



AB 11-20

AB 1-10

Figure 25. Specimens Employing Marion Cases for Glazed Ceramic-to-Kovar (top) and Glazed Ceramic-to-Steel (bottom) Seals.

BA 31 through 40

Aluminum bodies and covers were machined from bar stock as shown in Figure 23. Silastic 120, a silicone, was applied between cover and body, clamped and cured for 1 hour at 150°C. The seal length was 3.5 inches.

BB 1 through 10

Brass bodies and covers were machined from bar stock as shown in Figure 23. Kel F film, Type B, 0.005 inches thick, was clamped between the cover and body and made plastic by heating for 1 hour between 225°C. - 240°C. The seal length was 3.5 inches.

BB 11 through 20

Brass bodies and covers were machined from bar stock as shown in Figure 23. Nitro-Seal was applied between the cover and body, clamped and retained at room temperature. The seal length was 3.5 inches.

BB 21 through 30

Brass bodies and covers were machined from bar stock as shown in Figure 23. Araldite, Type XI, an epoxy adhesive, was applied between the cover and body, clamped and cured for one hour at 150°C. The seal length was 3.5 inches. (Selectron 5208 could not be used with brass because the presence of copper inhibits its setting, curing and polymerization.)

BB 31 through 40

Brass bodies and covers were machined from bar stock as shown in Figure 23. Silastic 120 was applied between cover and body, clamped and cured for one hour at 150°C. The seal length was 3.5 inches.

BS 1 through 10

A copper tube and a steel disc were silver soldered to the front of the steel Marion meter cases. Kel F dispersion NW 25 was reduced with xylol from 27% to 23% for brush application and applied to the back of the meter case. A steel cover was placed over the three 3/8 inch holes in the back of the case, clamped and baked for one hour between 225°C. - 240°C. The seal length was 6.3 inches. Details are shown in Figure 24.

BS 11 through 20

A copper tube and a steel disc were silver soldered to the front of the steel Marion meter cases. Kel F film, Type B, 0.005 inches thick, was clamped with a steel cover over three 3/8 inch holes in the back of the case and heated for one hour between 225°C. - 240°C. The seal length was 6.3 inches. Details are shown in Figure 24.

BS 21 through 30

A copper tube and a steel disc were silver soldered to the front of the steel Marion meter cases. Nitro-Seal was applied to a steel cover which was then clamped over the three 3/8 inch holes in the back of the case and left overnight at room temperature. The seal length was 6.3 inches. Details are shown in Figure 24.

BS 31 through 40

A copper tube and a steel disc were silver soldered to the front of the steel Marion meter cases. Selectron 5208 was applied to a steel cover which was then clamped over the three 3/8 inch holes in the back of the case and cured for one hour at 125°C. The length of seal was 6.3 inches. Details are shown in Figure 24.

BS 41 through 50

A copper tube and a steel disc were silver soldered to the front of the steel Marion meter cases. Silastic 120 was applied to a steel cover which was then clamped over the three 3/8 inch holes in the back of the case and cured for one hour at 150°C. The length of seal was 6.3 inches. Details are shown in Figure 24.

BS 51 through 60

A copper tube and a steel disc were silver soldered to the rear of the steel Marion meter cases. A steel cover with a 3/4 inch hole was silver soldered to the front of the case. A Neo-sil No. 1000-10 neoprene silicone composition seal was soft soldered into the hole using 50-50 grade solder with Rubyfluid Soldering Flux. The length of seal was 4.1 inches. Details are shown in Figure 24.

3. Class C - Gasket Seals

CA 1 through 10

Aluminum bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 0.139 inch thick "O" ring (Linear Incorporated Type MJ 70-0) in a rectangular cross section groove. The seal length was 4.3 inches.

CA 11 through 15

Aluminum bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 0.139 inch thick "O" ring (Linear Incorporated Type MJ 70-0) in a wedge shaped groove. The seal length was 4.3 inches.

CA 16 through 25

Aluminum bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick vulcanized black rubber gasket (35-45 durometer with a minimum elongation of 650%) in a rectangular cross section groove. The seal length was 4.3 inches.

CA 26 through 35

Aluminum bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick cork-neoprene gasket (Armstrong DC 100) in a rectangular cross section groove. The seal length was 4.3 inches.

CA 36 through 45

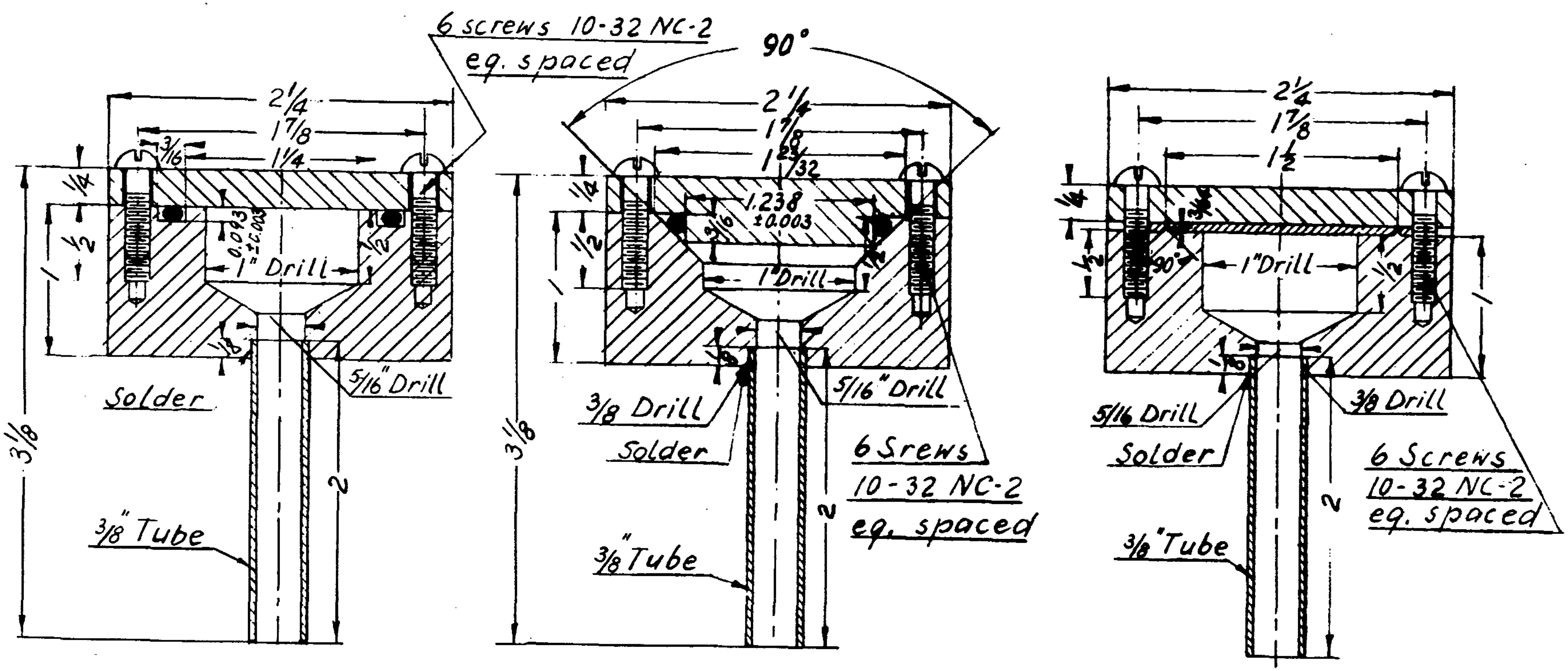
Aluminum bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick, asbestos fiber compound gasket (Johns-Manville Durabla) in a rectangular cross section groove. The seal length was 4.3 inches.

CA 46 through 55

Aluminum bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick cork-neoprene gasket (Armstrong DC 167) in a rectangular cross section groove. The seal length was 4.3 inches.

CB 1 through 10

Brass bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 0.139 inch thick "O" ring (Linear Incorporated Type MJ 70-0) in a rectangular cross section groove. The seal length was 4.3 inches.



CA 1-10
CA16-25
CA26-35
CA36-45
CA46-55
CB 1-10
CB11-20

CB26-35
CB36-45
CB46-55
CS 1-10
CS11-20
CS26-35
CS36-45

CA11-15
CB21-25
CS21-25

CS46-55
CS56-65

Figure 26

Fabrication of Specimens for Gasket Seals

CB 11 through 20
Brass bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick, cork-neoprene gasket (Armstrong DC 100) in a rectangular cross section groove. The seal length was 4.3 inches.

CB 21 through 25
Brass bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 0.139 inch thick "O" ring (Linear Incorporated Type MJ 70-0) in a wedge shaped groove. The seal length was 4.3 inches.

CB 26 through 35
Brass bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick, asbestos fiber compound gasket (Johns-Manville Durabla) in a rectangular cross section groove. The seal length was 4.3 inches.

CB 36 through 45
Brass bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick, black vulcanized natural rubber gasket (35-45 durometer with a minimum elongation of 650%) in a rectangular cross section groove. The seal length was 4.3 inches.

CB 46 through 55
Brass bodies and covers were machined from bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick cork-neoprene gasket (Armstrong DC 167) in a rectangular cross section groove. The length of seal was 4.3 inches.

CS 1 through 10
Steel bodies and covers were machined from cold rolled bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 0.139 inch thick "O" ring (Linear Incorporated Type MJ 70-0) in a rectangular cross section groove. The seal length was 4.3 inches.

CS 11 through 20
Steel bodies and covers were machined from cold rolled bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick, cork-neoprene gasket (Armstrong DC 100) in a rectangular cross section groove. The seal length was 4.3 inches.

CS 21 through 25
Steel bodies and covers were machined from cold rolled bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 0.139 inch thick "O" ring (Linear Incorporated Type MJ 70-0) in a rectangular shaped groove. The seal length was 4.3 inches.

CS 26 through 35
Steel bodies and covers were machined from cold rolled bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick vulcanized natural black rubber gasket (35-45 durometer with a minimum elongation of 650%) in a rectangular cross section groove. The seal length was 4.3 inches.

CS 36 through 45
Steel bodies and covers were machined from cold rolled bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers sealed the cover against a 1/8 inch thick asbestos fiber compound gasket (Johns-Manville Durabla) in a rectangular cross section groove. The seal length was 4.3 inches.

CS 46 through 55
Steel bodies and covers were machined from cold rolled bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers pressed a sheet of B. & S. gauge No. 24 copper on a 90° ridge on the steel body. The seal length was 4.7 inches.

CS 56 through 65
Steel bodies and covers were machined from cold rolled bar stock as shown in Figure 26. Six 10-32 machine screws with lock washers pressed a 1/16 inch sheet of lead on a 90° ridge on the steel body. The seal length was 4.7 inches.

4. Class D - Lapped Seals

DA 1 through 10

Aluminum bodies and covers were machined from bar stock as shown in Figure 23. Both were lapped with jeweler's rouge and water on a motor driven, lead lapping plate. The covers and bodies were free to rotate about their axes while being moved in and out on the radius of the rotating lead plate. Maximum scratch width and depth were less than one micron as measured with a microscope (1000x magnification) equipped with a vertical illuminator. The two lapped surfaces were pressed together by six 10-32 machine screws with lock washers. The length of seal was 3.9 inches.

DB 1 through 10

Brass bodies and covers were machined from bar stock as shown in Figure 23. Both were lapped with jeweler's rouge and water on a motor driven, lead lapping plate. The covers and bodies were free to rotate about their axes while being moved in and out on the radius of the rotating lead plate. Maximum scratch width and depth were less than one micron as measured with a microscope (1000x magnification) equipped with a vertical illuminator. The two lapped surfaces were pressed together by six 10-32 screws with lock washers. The length of seal was 3.9 inches.

DS 1 through 10

Steel bodies and covers were machined from cold rolled bar stock as shown in Figure 23. Both were hand lapped with American Optical Co. #303 1/2 and #309 emery on a cast iron lapping block. Scratches of approximately 10 microns in width and depth as measured with a microscope (1000x magnification)equipped with a vertical illuminator could not be prevented. The two lapped surfaces were pressed together by six 10-32 machine screws with lock washers. The length of seal was 3.9 inches.

SECTION VII

TEST PROCEDURES

A. Assembly of Specimens in Specimen Container

The following procedure was used in assembling the specimens into the specimen container for in- and out-leakage measurements.

1. Apply Dow-Corning vacuum stopcock grease to the test specimen tube.
2. Insert test specimen tube in hole of specimen container cover (Figure 27).
3. Tighten the four screws on the small flange. (The "O" ring is compressed and a vacuum tight seal is obtained between the specimen tube and specimen container cover.)
4. Attach the vacuum rubber tubing to the test specimen tube.
5. Attach the vacuum rubber tubing to the specimen container tube.
6. Assemble cover on specimen container. (Figure 28). Tighten wingscrews so that the large "O" ring is compressed and a vacuum tight seal achieved.

Vacuum stopcock grease was used on all vacuum rubber tubing and "O" ring joints. For use with the Gross Leak Meter, one specimen container may be used for both in- and out-leakage. With the High Sensitivity Leak Meter, it was advisable to use two separate specimen containers, one for in-leakage and the other for out-leakage. Sorption of hydrogen by the specimen container may be sufficient to give a false indication of a leak.

B. High Sensitivity Leak Meter (Figure 1)

For in-leakage measurement, the specimen tube was connected to manifold toggle valve 2 while the specimen container tube was connected to the T section adjoining the hydrogen inlet valve as shown on the left in Figure 29. For out-leakage measurement, the specimen container tube was connected to manifold toggle valve 2 and the specimen connected to the T section, as shown in the center in Figure 29.

The connections were made with vacuum rubber tubing. On both in- and out-leakage, the rubber tubing connected to the T section was at one atmosphere hydrogen pressure during the run and absorbed a substantial amount of hydrogen. It was never subsequently used for the manifold connection. It was also important that an absolute minimum of rubber tubing was exposed to the inside of the leak meter at the manifold toggle valve connection.

The complete operating procedure is given, starting with the fore-pumps off and the palladium oxidized. Most of these steps can be eliminated in normal operation.

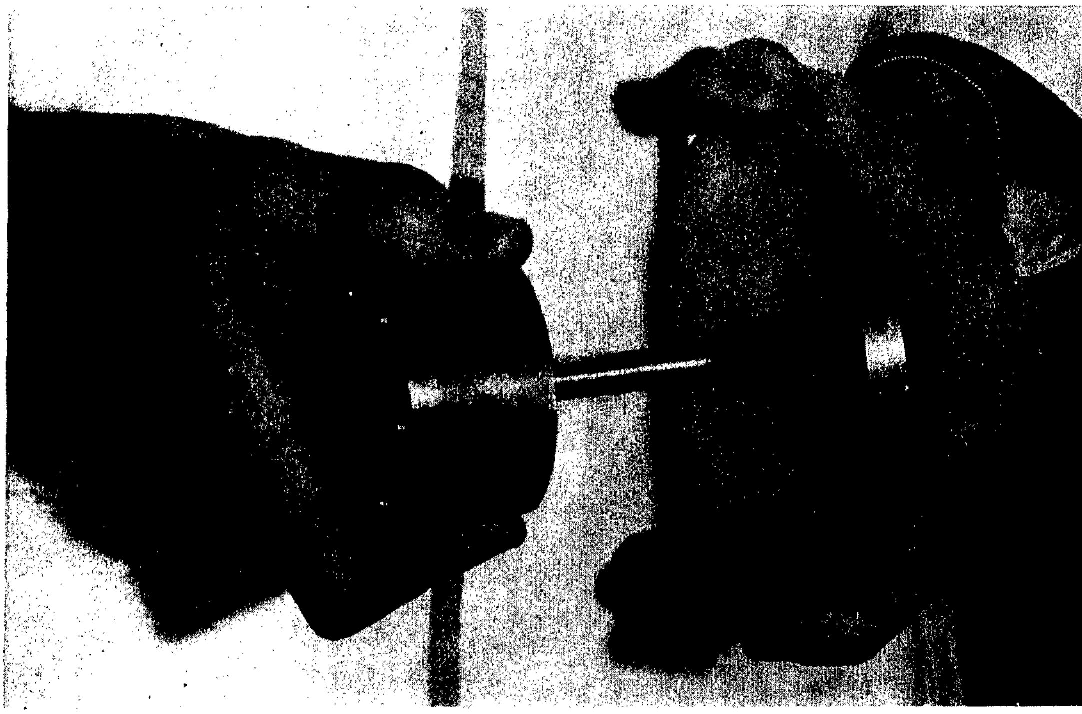


Figure 27. Assembly of Test Specimen to Cover of Specimen Container.

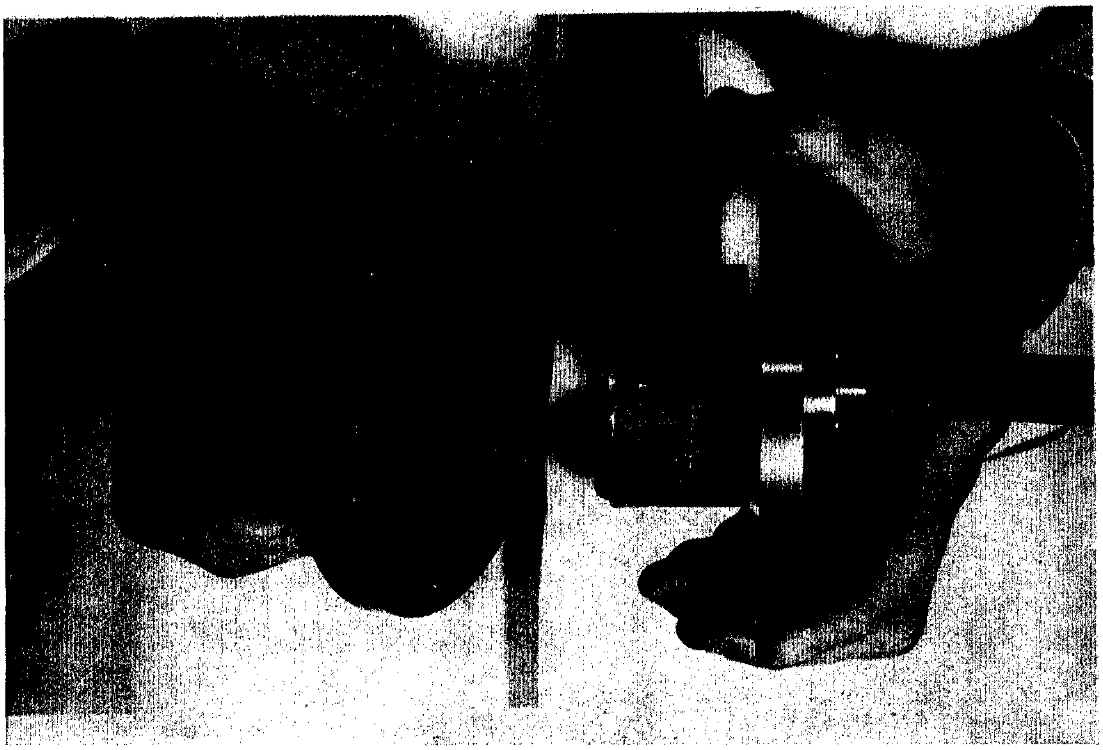


Figure 28. Completion of Specimen Container Assembly. At the right, the test specimen has already been assembled to the cover. Two lengths of vacuum tubing have been connected; the one at the right to the test specimen and the one at the left to the specimen container.

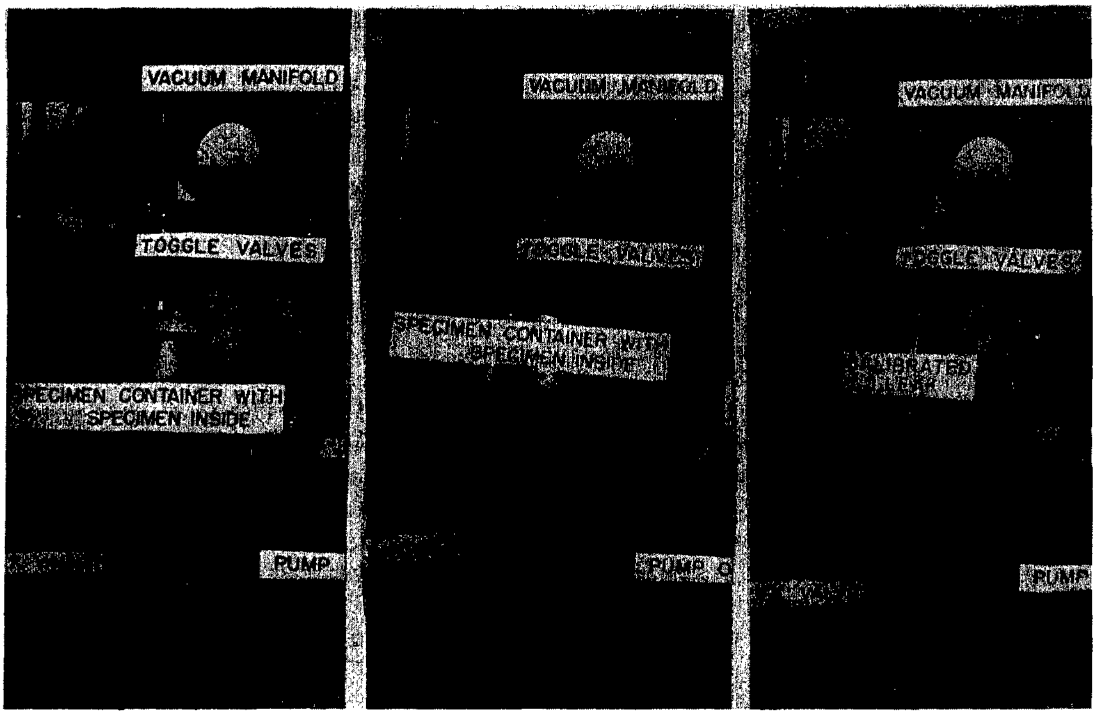


Figure 29. Connections to the Vacuum Manifold for Measurements with High Sensitivity Leak Meter. From left to right, they represent the connections for in-leakage, out-leakage, and calibration determinations.

OPERATING PROCEDURE

1) With Valve B closed and Valves A and C open, the fore-pumps are turned on and allowed to warm up. About 30 minutes is required.

2) The flask around the cold trap is filled with a dry ice-acetone mixture.

3) After the trap has had sufficient time to cool, Valve B is opened and the trap evacuated.

4) After about 15 minutes, another flask containing liquid nitrogen is quickly substituted for the flask containing the dry ice-acetone mixture.

5) The thermocouple gauge is turned on and adjusted to its rated heater current.

6) After the thermocouple gauge reaches 135 on the 200 micro-ampere meter described in Figure 5, and with the meter switch in the "Emission" position, the ion gauge control circuit is turned on. After the circuit warms up, the emission is set with the "Emission Adjust" knob to obtain the required 6.0 watt ion gauge plate dissipation.

7) The air is cleared from the line up to the hydrogen source valve by flushing hydrogen through it. The regulator on the standard hydrogen tank is set at a few lbs/in^2 above atmospheric pressure. The hydrogen source valve is closed after flushing, the hydrogen pressure remaining above atmospheric.

8) Valve B is closed. The hydrogen ballast container is then evacuated through the open hydrogen inlet valve and pumpout valve. The top of the T section is closed during evacuation. After the thermocouple gauge reaches 100, the hydrogen inlet valve is closed and hydrogen let into the ballast container by slowly opening the hydrogen source valve. An excess hydrogen pressure of a few lbs/in^2 insures no air leakage into the container.

9) Calibrated leaks are connected by sections of vacuum rubber tubing between manifold toggle valve 2 and the T section as shown on the right in Figure 29. Calibration runs are made until the hydrogen ion gauge reaches maximum sensitivity as described in Calibration of the High Sensitivity Leak Meter. The procedure used for measuring the leakage rate of the calibrated leaks is identical to that used for measuring test specimen leakage. Calibration checks are made once a week to insure the validity of measurements.

10) The specimen and specimen container are connected to the system for in- or out-leakage.

11) The ion gauge meter switch is turned to the "Pressure" position. The meter is set at zero on the scale being used by depressing the zero set button and using the zero adjust control. Leak measurement may be started when the meter reads 0.7 or less on the 1 scale (highest sensitivity scale).

12) Valves B and C are closed before evacuating the specimen and specimen container through manifold valve 2 and the pumpout valve. Valve B must be closed to prevent the air from oxidizing and desensitizing the palladium.

13) After the thermocouple gauge reaches 140, Valve B is opened. This speeds up evacuation by allowing the trap to condense the condensible vapors, decreasing the pressure still further.

14) If no hydrogen has contacted the hot palladium window in the previous 20 minutes, the gauge is sensitized by a small shot of hydrogen from the hydrogen generator. Valve B is closed and the hydrogen generator button depressed until the meter reads 5 on the 10 scale. Valve B is then opened and this hydrogen is pumped out in less than a minute. (This procedure is unnecessary if hydrogen has recently contacted the hot palladium).

15) When the thermocouple gauge reads 150, Valve A is closed and a one minute control check is made. If the meter reading does not increase during this period, no hydrogen source is present anywhere in the system which might be mistaken for a leak. The pumpout valve and the hydrogen source valve are then closed.

16) The run is started by opening the hydrogen inlet valve, starting the timer, and reducing the hydrogen pressure to one atmosphere by momentarily opening the pressure release valve. From the leak meter reading, the operator decides before 100 seconds have elapsed if an equilibrium run is to be made. If an equilibrium run is not made, he decides from the meter reading at 100 seconds whether to make a 100, 200 or 300 second timed run. The criteria adopted were as follows:

Meter Reading	Time	Run to be Made
200	less than 100 sec.	Equilibrium-Open Valve A
100-200	100 sec.	100 sec. Timed-Stop run.
30-100	100 sec.	200 sec. Timed
below 30	100 sec.	300 sec. Timed

The leakage rate in std. cc. of air/yr. is obtained directly from the meter reading using the appropriate calibration curve.

17) Manifold toggle valve 2 and the hydrogen inlet valve are closed. Valves A and C leading to the forepumps are opened to pump the hydrogen out of the leak meter. The hydrogen source valve is momentarily opened, increasing the hydrogen pressure in the ballast container to a few lbs/ in^2 above atmospheric.

18) The specimen under test is removed. The next test specimen is inserted and the procedure repeated, starting with step (10).

Dow-Corning vacuum stopcock grease is used on all rubber tubing and "O" ring joints.

In shutting down for the night, the High Sensitivity Leak Meter control circuit is turned off and the liquid nitrogen replaced with the dry ice-acetone mixture. Dry ice-acetone is used because it remains cold much longer than liquid nitrogen, providing sufficient powdered dry ice is used. If the trap is not kept cold, the condensed contaminants in the trap will evaporate and recondense on the palladium. Valves A, B, and C are left open and both forepumps left running.

The starting up procedure consists of replacing the dry ice-acetone with liquid nitrogen and starting directly from step (4).

Should the ion gauge ever become flooded with hydrogen, the source of hydrogen is first shut off. Valves A and C are immediately opened to pump the hydrogen out of the ion gauge. The ion gauge control circuit is not turned off for this would trap the hydrogen in the gauge.

C. Gross Leak Meter (Figure 9)

For in-leakage measurement, the specimen tube is connected to one of the manifold toggle valves while the specimen container tube is connected to the T section adjoining the blowback valve.

For out-leakage measurement, the specimen container tube is connected to one of the manifold toggle valves and the specimen tube is connected to the T section.

The connections are made with vacuum rubber tubing with vacuum stopcock grease being used at all joints.

OPERATING PROCEDURE

1) The pump pulley is turned over by hand in the direction of the arrow and then the pump switch is turned on.

2) A small amount of distilled water is introduced into each capillary tube to form a plug about 1 mm. long. A medicine dropper is satisfactory for introducing water into the large capillary while the head of a pin holds sufficient water for the small capillary.

3) The specimen and specimen container are connected to the system for either in- or out-leakage.

4) With the blowback valve open, the water plug in the capillary tube is blown to a position about an inch beyond the scale.

5) The manifold toggle valve is opened to evacuate the specimen (or specimen container when out-leakage is being measured).

6) The blowback valve is closed after the pump quiets down indicating the specimen is evacuated.

7) The movement of the water plug is observed. As it passes the zero scale reading, the timer is started. The timer is usually stopped as the water plug moves either 5 or 10 centimeters, depending on the rate of flow.

8) The blowback valve is then opened to stop the movement of the water plug.

9) The leakage rate is computed by substituting in the appropriate equation the time, t, and the distance, d, of the water plug movement.

10) The specimen container is disassembled and the procedure repeated on the next specimen, starting with step (3).

11) To shut down, the forepump is turned off and air admitted into the vacuum manifold. The water plugs are then removed from the capillary tubes.

D. Environmental Tests

The test specimens were exposed to the environmental conditions in the following order and the indicated measurements made:

1. Room Conditions

The in-leakage and out-leakage of each specimen were measured before exposure to any environmental conditions.

2. Pressure

Paragraph 4.3.3.4 of Exhibit No. MCREE-752 specifies "External pressures ranging from 0 to 70,000 feet or 29.92 inches of mercury down to 1.32 inches of mercury absolute, with an internal pressure of 29.92 inches. Internal pressures ranging up to 60 inches of mercury absolute, with external pressure of 29.92 inches". Paragraph 4.3.3.1 specifies "Two atmospheres differential on opposite faces of the seal at a temperature of 25°C."

The two atmosphere internal pressure differential was obtained by connecting the test specimen directly to a pressure source set at 30 psi gauge pressure and maintaining atmospheric pressure externally. The two atmosphere external pressure differential was obtained by pressurizing the specimen container surrounding the specimen at 30 psi gauge pressure and maintaining atmospheric pressure internally.

In- and out-leakage measurements were made after the above cycle while maintaining external pressures of approximately 29.92 inches and internal pressures less than 1.32 inches of mercury absolute and vice versa.

3. Humidity

Test specimens were stored in a humidity chamber which maintained 100% relative humidity at 25° ± 5°C. The differential of the thermostatic control was 10°C. so that the temperature was variable by ± 5° from 25°C. for each cycle before the heating element was cut in or off. Condensation occurred in the test chamber each time the heating element was cut off and the temperature decreased. After 30 days the specimens were removed and in- and out-leakage measured.

4. Vibration

For the specified cycling, the vibrator used was the Model 10-RA Vibration Fatigue Testing Machine made by the All American Tool and Manufacturing Co. The test specimens were vibrated for 90 minutes in each of three mutually perpendicular planes while the frequency of vibration varied from 10 to 55 cycles per second at an amplitude of 0.06 inch total excursion.

In- and out-leakage were measured after the vibration tests.

5. Temperature Cycling

Test specimens were exposed to three temperature cycles between -65°C. and 200°C. as follows:

a) Room temperature
b) -65°C.; in deep freeze
c) 200°C.; in oven
d) -65°C.; in deep freeze
e) 200°C.; in oven
f) -65°C.; in deep freeze
g) 200°C.; in oven
h) Room temperature

The test specimens were retained in both the deep freeze and the oven for a sufficient length of time to attain the specified temperatures. An alumel-chromel thermocouple was attached to one of the specimens in both the oven and deep freeze to determine when thermal equilibrium was obtained.

In the oven, an external fan and baffle were provided for good circulation. The specimens were shielded from direct radiation from the heating elements. In the deep freeze, test specimens were set on their bases to insure good thermal contact and to minimize the cool-down period.

After completion of the temperature cycling, in- and out-leakage was measured. Thus, there were 10 measurements for each specimen, 5 in-leakage and 5 out-leakage, or 4,490 measurements for all the test specimens.

SECTION VIII

ANALYSIS OF NON-DESTRUCTIVE TESTING METHODS

The problem of non-destructive testing of sealed electronic components and assemblies on a production line basis was investigated. The solution resolves itself into two general approaches:

(a) Sealing into the component of a test gas to which the detector is sensitive at atmospheric or slightly higher pressure.

(b) Providing access to the inside of the component so that the detector sensitive gas may be introduced at the time of measurement.

The following discussion cites the reasons for providing access to the inside of the component rather than the sealing of a test gas into the component.

There are several objections to sealing a test gas into the component.

The test gas must, of course, be one to which the detector is sensitive. Since it is desirable to have selective sensitivity in a detector, this necessarily means that there is only one type of test gas to be sealed in the component. However, this particular gas might not also be the same gas needed to give maximum life to the equipment inside the component and indeed might even be corrosive. It is also conceivable that different equipment inside of the many types of sealed components might require different protective atmospheres for maximum life. Even if different gases are not required inside the components at the present time, there is no assurance they will not be needed in the future. Should the problem arise then, the standards of measurement adopted now would have to be changed.

A second objection to sealing hydrogen, for example, into a component is the danger of explosion if such sealing is accompanied by high temperature.

The third and probably most important objection to sealing a gas in a component is that it does not lend itself to quantitative measurements of leakage rates. The amount of test gas left in the component at the time of measurement will depend on the size of the leak, the pressure at which the gas was introduced, the time between sealing and measurement, and the pressure conditions outside the component during that period. The larger the leak, the more test gas would leak out before the measurement so that there would be less test gas inside at the time of measurement. This would give an indication of

a smaller leak than actually existed. The leak might be so large that all the test gas would leak out before the measurement was made. In this case, there would be no test gas left to detect and an erroneous reading of zero leakage would be obtained.

Providing access to the inside of the component, in our opinion, is the most reliable method of measuring the leakage rate quantitatively. We utilized this approach in two different forms for measuring the leakage rates of the sealed components submitted to us by Wright Air Development Center.

One method required a component with a smooth flat surface for an "O" ring seal. A small hole inside the "O" ring seal provided access into the component and was sealed off after measurement. Two "O" ring adaptors used on different types of components are shown in Figure 30. The assembly drawings of these adaptors are shown in Figure 31.

Figures 32 and 33 show adaptors on six different types of components. Different brackets are used to hold the "O" ring in the adaptor firmly against the smooth, flat surface, providing a seal. On the left of each of these photographs an identical component (with a 1/8" hole drilled in the top) is shown prior to attachment of the "O" ring adaptors. These holes should be put in the container before the manufacturer assembles the electrical components inside the container. The flat surface which the "O" ring seals should be free of scratches, solder, paint or anything else which might prevent a good seal. If finishing of this surface is necessary, it is best to do this before sealing to prevent abrasives from getting inside the container. Stopcock grease was used on the "O" ring to insure a good seal. If the component is to be filled with a liquid, this must be done after the measurement, through the 1/8 inch hole on top.

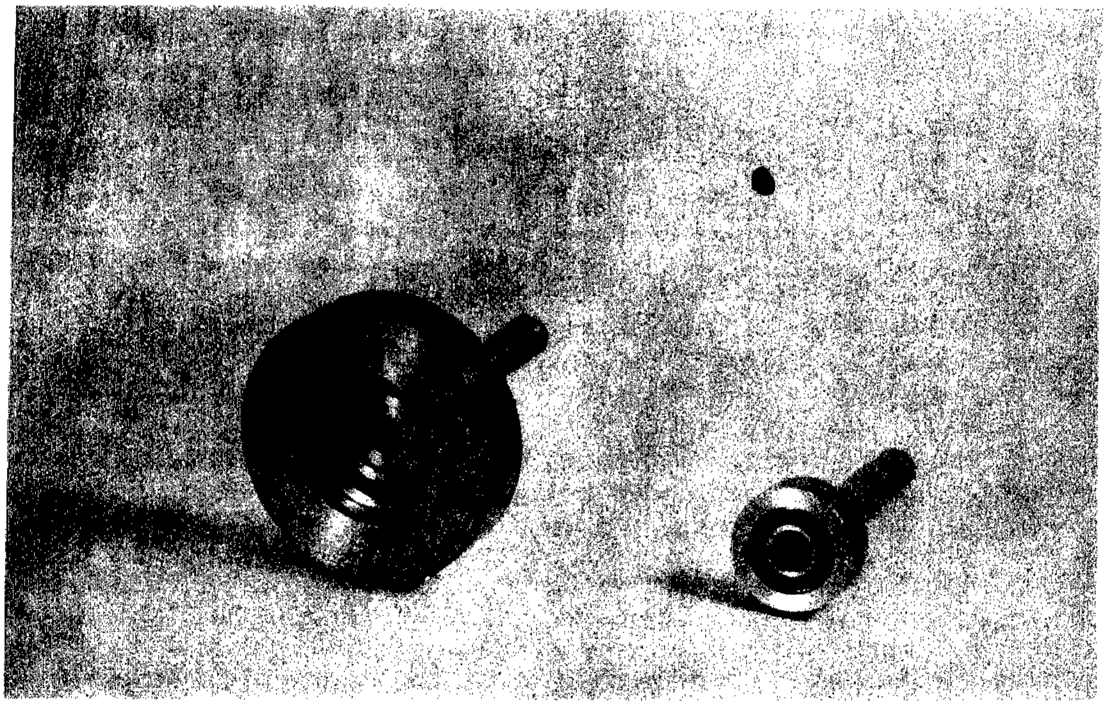


Figure 30. Two "O" Ring Adaptors for Providing Access to Inside of Component.

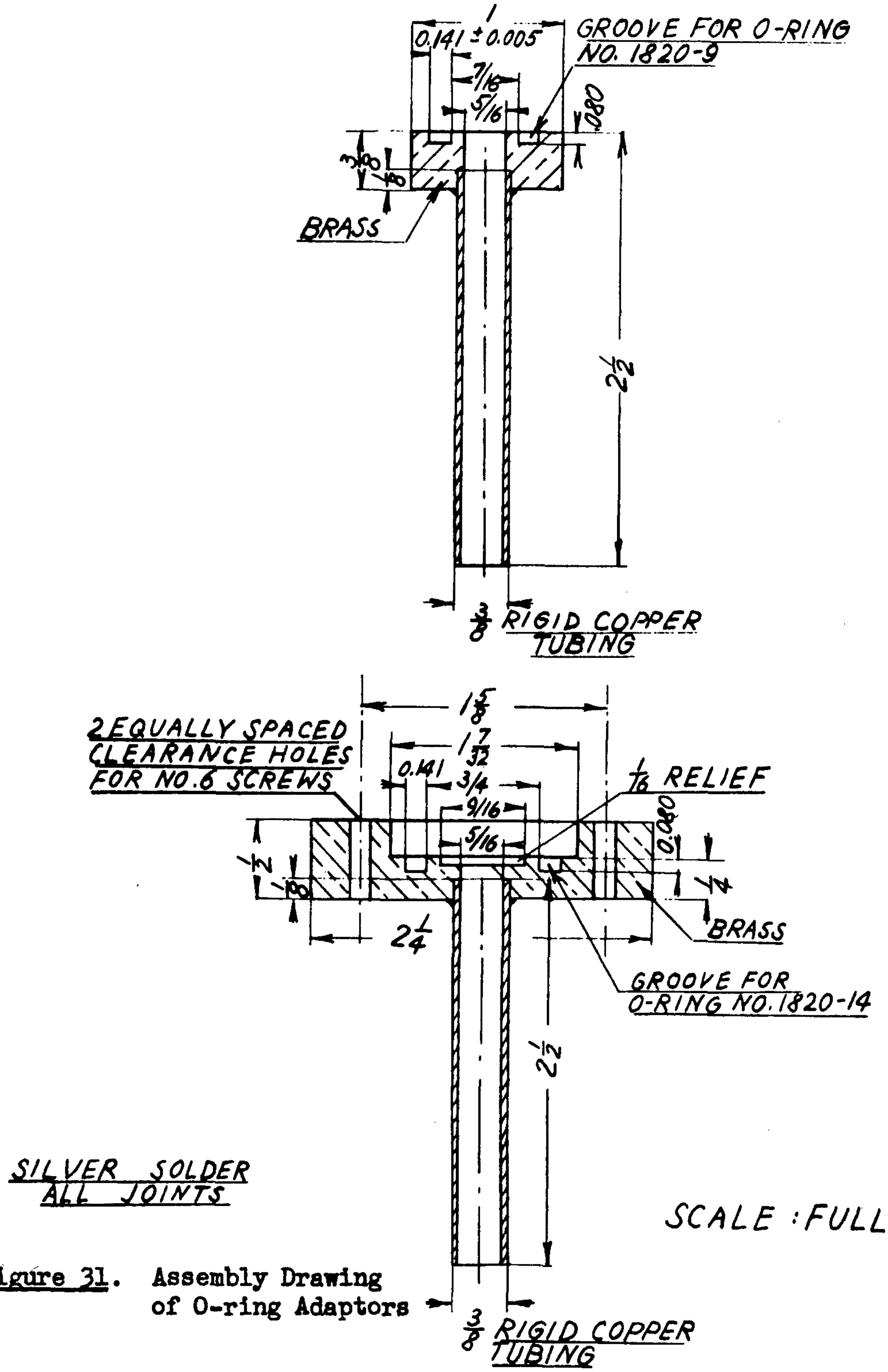


Figure 31. Assembly Drawing of O-ring Adaptors

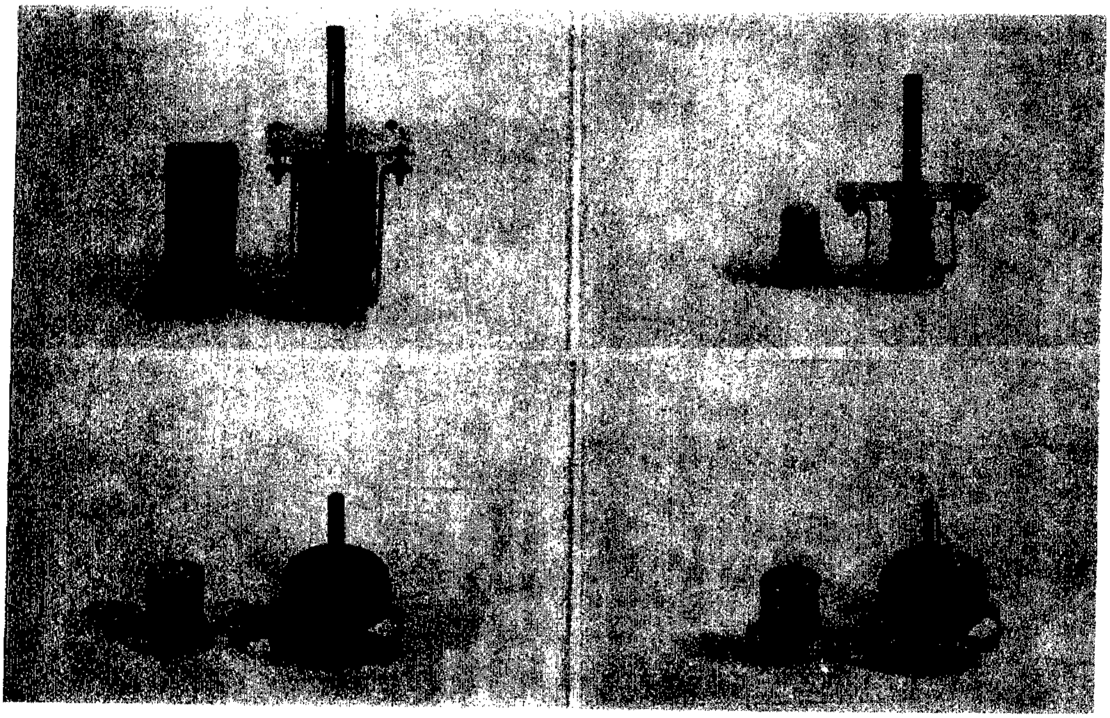


Figure 32. Assembly of Four Components with "O" Ring Adaptors. The components are at the left and the assemblies at the right.

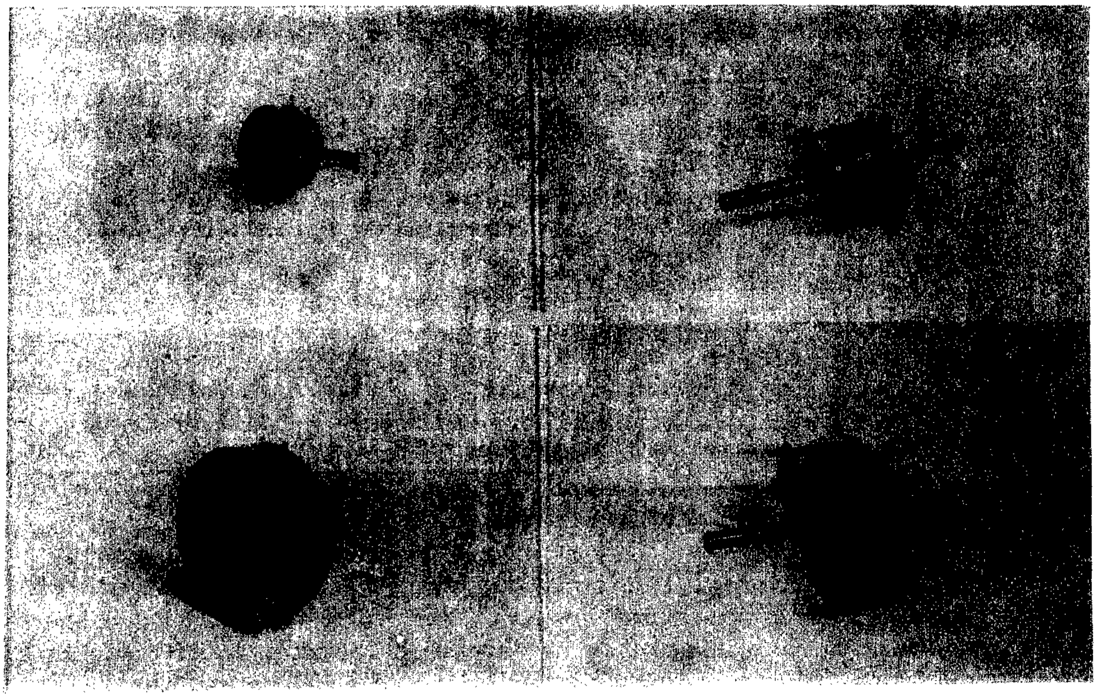


Figure 33. Assembly of Two Components With "O" Ring Adaptors. The components are at the left and the completed assemblies at the right.

The other method involved using a component with a flexible copper pump out tube as is shown in the lower left corner of Figure 34. (The other three assemblies in Figure 34 are three other types of components using the "O" ring adaptors as in Figures 32 and 33. The flexible copper tubing should be free of grooves and scratches for 3/8 inch back from the open end.) Rubber tubing, 1/16 inch I.D., is slipped over the 1/8 inch O.D. flexible copper tubing with the aid of stop cock grease to insure a tight seal. The other end of the rubber tubing is pushed over a short section of 1/8 inch copper tubing soldered into a short length of rigid 3/8 inch copper tubing. If the component is to be filled with a liquid, this must be done after the measurement through the 1/16 inch diameter hole in the 1/8 inch tubing.

The "O" ring adaptor seal was tested for tightness on each of the different types of components. Before the 1/8 inch hole was drilled in the components, the adaptors were attached as in Figure 32, 33, and 34. A zero leakage rate measurement for each of these types of components furnished proof that the "O" ring seal itself did not leak.

The upper photograph in Figure 35 shows a component with an "O" ring adaptor ready for insertion into the specimen container. This particular component before assembly is shown in the upper left corner of Figure 32. Rubber tubing is shown attached to the "O" ring adaptor tube which extends through the lid of the specimen container.

The lower photograph in Figure 35 shows a component with a flexible copper pump out tube ready for insertion into the specimen container. This particular component before assembly is shown in the lower left corner of Figure 34. The cylindrical tube betweeen the component and the lid serves to keep the component from pinching the connecting rubber tubing. The holes in this tubing assure that the pressure here will be no different than in any other part of the specimen container. Rubber tubing is shown attached to the 3/8 inch copper tube which extends through the lid of the specimen container.

After insertion of either type of component into the specimen container, the lid was sealed to the specimen container with an "O" ring by four wing screws, not shown. Details of the specimen container are shown in Figure 20.

The Gross and Portable Leak Meter were used for measuring leaks too large to be measured on the High Sensitivity Leak Meter. They were also used to measure leaks when the components were filled with a liquid which would be pumped out by evacuation. Only one side of the component must be evacuated for measurement on the Gross or Portable Leak Meter, whereas both sides must be evacuated on the other leak meter.

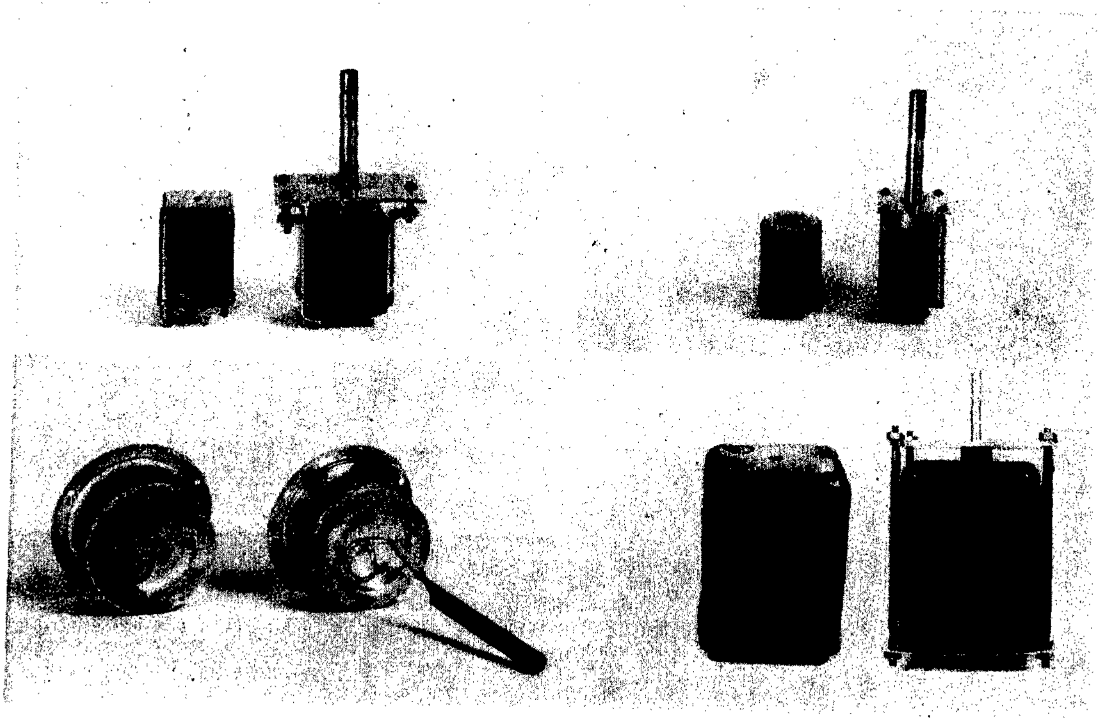


Figure 34. Four Additional Component Assemblies for Leakage Rate Measurements. The component at the lower left has a flexible copper pumpout tube to which a short length of rigid copper tubing has been connected. The other assemblies have "O" ring adaptors.

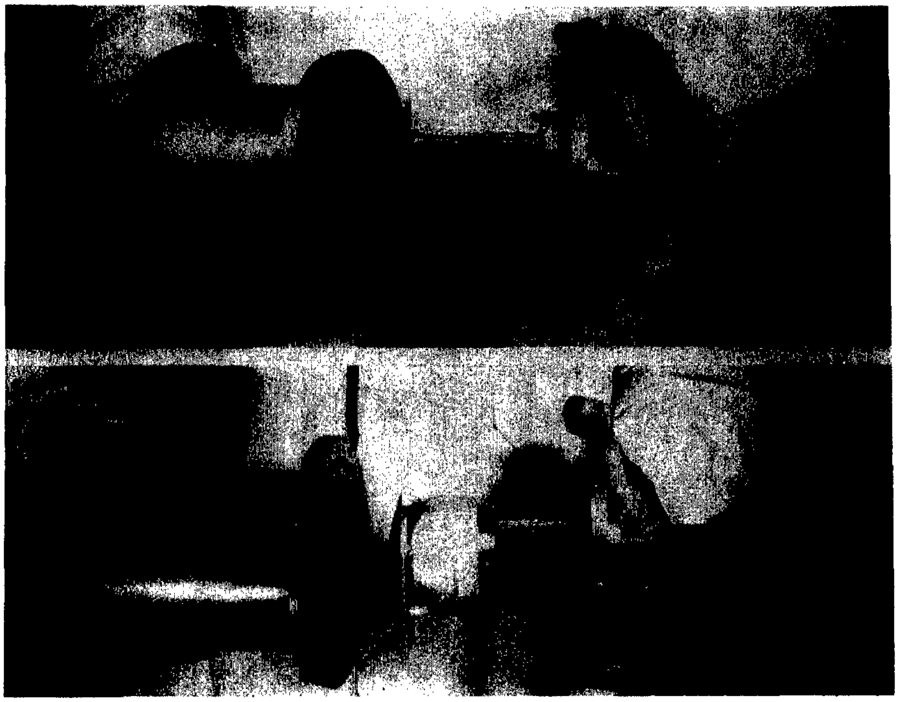


Figure 35. Insertion of Assembled Components into Specimen Container for Leakage Rate Evaluation.

If the component did not contain any liquid or had a small suspected leakage rate, the specimen container was attached to the High Sensitivity Leak Meter in the familiar out-leakage position. The air was evacuated from the test specimen before hydrogen was admitted for measurement. After measurement of the leakage rate, the hydrogen was again evacuated and air or some other gas or liquid could be admitted to the component before sealing. If it is intended that the leakage rate be measured again at some future date, the use of any liquid should, of course, be avoided. The leak meter might be contaminated if it were exposed to components of high vapor pressure such as varnishes or wires, oil or other substances likely to be encountered inside the sealed components. For this reason, only out-leakage was measured for then only the outside of the sealed component was exposed to the leak meter. Since this is usually a metal surface with few re-entrant cracks, there was little out-gassing.

After measurement of the leakage rate of the component, it was necessary to seal the hole which provided access into the container. This sealing must be positive, as there is no quantitative measure of its tightness. This sealing will be positive if the following techniques are employed for both types of components:

1. The 1/8 inch hole as shown in the components in Figure 32 and 33 should first be plugged. If the plug has a shoulder similar to a rivet, it cannot drop through the hole into the container. It should fit snugly into the hole so there will be sufficient surface tension to keep the molten solder from dripping inside. If necessary, a suitable flux should be applied before heating the plug and container top. Soft solder should then be applied to these surfaces after heating, not to the soldering iron. This will help insure that a cold solder joint does not result. A slight depression in the container immediately next to the hole will allow the soft solder to form a small puddle over the shoulder of the plug.

2. The flexible copper pump out tube shown on the type of components in the lower left corner of Figure 34 should first be pinched tight at the open end. Flux should then be used if necessary, followed by dipping the pinched off portion into a pot of molten soft solder. Sufficient time should be allowed before withdrawing to permit the pinched off portion of the tube to reach the temperature of the solder.

Visual inspection of soft solder seals of this geometry is virtually foolproof. With very little training, even inexperienced personnel can tell the difference between a perfect seal and a suspicious seal over this limited area. If any suspicious seals occur, the component can be resealed until a perfect seal results.

SECTION IX

SEALED ELECTRONIC COMPONENTS SUBMITTED BY WRIGHT AIR DEVELOPMENT CENTER

Photographs of each type of sealed electronic component submitted to our laboratories for measurement are shown in Figures 32, 33, and 34. The components were marked serially upon arrival to facilitate identification. The following table correlates all identifying markings with the photographs.

IDENTIFICATION OF COMPONENTS WITH PHOTOGRAPHS

Sample No.	Component	Identifying Marking	Photograph
1	Relay	None	Figure 32, upper left
2	Relay	None	Figure 32, upper left
3	Relay	None	Figure 32, upper right
4	Relay	None	Figure 32, upper right
5	Relay	Allied Control, Inc., MH-18, 26.5V. D.C.	Figure 32, lower left
6	Relay	Allied Control, Inc., MH-18, 26.5V.D.C.	Figure 32, lower left
7	Relay	Allied Control,Inc., MH-18, 26.5V.D.C.	Figure 32, lower left
8	Relay	Allied Control, Inc., MH-18, 26.5V.D.C.	Figure 32, lower left
9	Relay	Allied Control, Inc., MH-18, 26.5V.D.C.	Figure 32, lower left
10	Relay	Allied Control, Inc., MH-18, 26.5V.D.C.	Figure 32, lower left
11	Relay	Allied Control, Inc., MH-18, 26.5V.D.C.	Figure 32, lower left
12	Relay	Allied Control, Inc., MH-18, 26.5V.D.C.	Figure 32, lower left

IDENTIFICATION OF COMPONENTS WITH PHOTOGRAPHS - Cont'd.

Sample No.	Component	Identifying Marking	Photograph
13	Relay	Allied Control, Inc., MH-18, 26.5V.D.C.	Figure 32, lower left
14	Relay	Allied Control, Inc., MH-18, 26.5V.D.C.	Figure 32, lower left
15	Relay	None	Figure 34, upper left
16	Relay	None	Figure 32, lower right
17	Relay	None	Figure 32, lower right
18	Relay	None	Figure 34, upper left
19	Output Transformer	UTC B-144TA (Wright Field #41)	Figure 34, upper right
20	Output Transformer	UTC B-144TA (Wright Field #41)	Figure 34, upper right
21	Output Transformer	UTC B-144TA (Wright Field #43)	Figure 34, upper right
22	Output Transformer	UTC B-144TA (Wright Field #43)	Figure 34, upper right
23	Output Transformer	UTC B-144TA (Wright Field #34)	Figure 34, upper right
24	Potentiometer	Fairchild Camera & Instrument Co., Ser. #215	Figure 33, lower left
25	Potentiometer	Fairchild Camera & Instrument Co., Ser. #194	Figure 33, upper left
26	Instrument Case Assembly	Electro Tec Corp., #3A1 4	Figure 34, lower left
27	Instrument Case Assembly	Electro Tec Corp., #3B1 8	Figure 34, lower left

IDENTIFICATION OF COMPONENTS WITH PHOTOGRAPHS - Cont'd.

Sample No.	Component	Identifying Marking	Photograph
28	Instrument Case Assembly	Electro Tec Corp., #3B1 7	Figure 34, lower left
29	Instrument Case Assembly	Electro Tec Corp., #3A1 3	Figure 34, lower left
30	Instrument Case Assembly	Electro Tec Corp., #3B3 5	Figure 34, lower left
31	Instrument Case Assembly	Electro Tec Corp., #3B3 4	Figure 34, lower left
32	Instrument Case Assembly	Electro Tec Corp., #3B1 4	Figure 34, lower left
33	Instrument Case Assembly	Electro Tec Corp., #3B3 9	Figure 34, lower left
34	Instrument Case Assembly	Electro Tec Corp., #3B1 5	Figure 34, lower left
35	Instrument Case Assembly	Electro Tec Corp., #3B1 10	Figure 34, lower left
36	Instrument Case Assembly	Electro Tec Corp., #3B1 9	Figure 34, lower left
37	Instrument Case Assembly	Electro Tec Corp., #3B1 6	Figure 34, lower left
38	Filament Transformer	Chicago Transformer Co., #16069	Figure 34, lower right
39	Filament Transformer	Chicago Transformer Co., #16069	Figure 34, lower right
40	Filament Transformer	Chicago Transformer Co., #16069	Figure 34, lower right
41	Filament Transformer	Chicago Transformer Co., #16069	Figure 34, lower right
42	Filament Transformer	Chicago Transformer Co., #16069	Figure 34, lower right
43	Filament Transformer	Chicago Transformer Co., #16069	Figure 34, lower right

SECTION X

RESULTS OF LEAKAGE RATE MEASUREMENTS

A. Method of Averaging

The leakage rates of the 449 fabricated test specimens were measured a total of 10 times for in- and out-leakage before and after the specified environmental tests. Each of the 4490 leakage rates was divided by the corresponding length of seal so that it might be expressed as leakage per inch of seal. The resulting Leakage Rate Measurements per Inch of Seal are listed in Table No. 1 in the Appendix.

As can be seen from the data, there are many cases where there are non-typical leakage rates within each group. For example, in the group AAS 1 through 10, nine specimens have essentially no leakage at all while one specimen, AAS 9, exhibits leakage rates between 16 and 180,000 std. cc. of air/yr/inch of seal on the various tests. Intelligent seal evaluation requires that the proper method of averaging be chosen.

Clearly, simple arithmetical averaging as contemplated and used earlier in the project is not the answer. Arithmetical averaging would give an average in-leakage rate after the temperature tests of 18,000 std. cc. of air/yr/inch of seal for AAS 1 through 10. This average might lead one to believe that the average specimen of this type would have a leakage rate of 18,000 std. cc. of air/yr/inch of seal for this test. Actually, nine of the specimens had zero leakage rates with only one having a leakage rate of 180,000 std. cc. of air/yr/inch of seal.

A grading system of averaging was adopted instead of arithmetical averaging. In the case just cited, the grading method of averaging shows that 90% of the seals are very good seals while 10% are very poor. This, of course, is a much truer representation of the facts. The following standards for grading the quality of the seals and averaging the results was chosen:

Grade	Leakage Rate (in std. cc. of air/yr/inch of seal)
A	0-1*
B	1-100*
C	100-10,000*
D	10,000 and higher
* = upper limit not included	

Each specimen was graded according to its in-and out-leakage rate for each environmental test. The percentage in each grade for each environmental test was computed after totaling the number in each grade for each test. For example, Specimens AAS 1 through 10 had in- and out-leakage rates after temperature tests which classified them as 18 Grade A and 2 Grade D seals. Thus, 90% were Grade A seals after this test while 10% were Grade D seals. These percentages are incorporated in Table No. 2, the Performance Rating of Specimens. Besides listing the percentage in each grade for each environmental test, the table also gives the average for all the environmental tests for each specimen type. For example, for Specimens BS 11 through 20, 90% were Grade A seals at room conditions, 90% after pressure exposure, 80% after humidity exposure, 80% after vibration exposure, and 10% after temperature exposure. Thus, the overall average rating was $\frac{90 + 90 + 80 + 80 + 10}{5} = 70$. These average ratings, listed in the last column of Table No. 2, are presented graphically in the "Specimen Performance Charts" (Table No. 3).

B. Evaluation of Seals Tested

1. Class A (fusion type) seals

   a) Aluminum to aluminum - aluminum solder
   Specimens AAA 1 through 10 were 100% Grade A seals for all environmental tests.

   b) Brass to brass

      1) Soft solder
      Specimens AAB 11 through 20 were 100% Grade A seals for all tests except the temperature test. Leaks were probably caused by the high temperature cycle at 200°C. for this is between the 183°C. - 216°C. melting range for 50-50 grade solder.

      2) Silver solder
      Specimens AAB 1 through 10 were 100% Grade A seals for all environmental tests.

   c) Steel to steel

      1) Soft solder
      Specimens AAS 45 through 54 were 100% Grade A seals for all environmental tests.

      2) Silver solder
      Specimens AAS 1 through 10 were Grade A seals except for AAS 9. All specimens were examined visually after fabrication. Any specimens with suspicious seals were either resealed or rejected. The fact that AAS 9 leaked after passing the visual inspection test does not necessarily mean that visual inspection of silver solder joints was not trustworthy. It does emphasize that solder fillet geometry is very important for visual testing. A smooth fillet type

joint like those joining all the specimen tubes to the specimens is ideal for visual inspection. Specimens AAS 11 through 20 were 100% Grade A seals for all tests. Neither the insert type cover nor the overhand cover used in these two sets of specimens is recommended for positive visual inspection.

3) Gas welded
Specimens AAS 21 through 30 show that it is possible to obtain Grade A seals (almost 40% of these gas welded seals) by gas welding but considerable experience and skill in vacuum tight welding might be required to obtain a high percentage of good seals. Extremely few welders are familiar with the difficulties of vacuum tight welding and the importance and technique of completely eliminating flux inclusions. Although these specimens were welded by a commercial welding firm, vacuum tight welds can be obtained consistently by welders specially trained for this type of welding.

4) Arc welded
Specimens AAS 31 through 44 show the difficulty in obtaining vacuum tight seals by arc welding (no Grade A seals were obtained). As in gas welding, very few welders are familiar with the technique required to produce vacuum tight seals. Although these specimens were welded by a commercial welding firm, vacuum tight welds can be obtained consistently by welders specially trained for this type of welding. It is much easier to obtain welds free of flux inclusions by using an inert gas arc welder.

d) Glass to steel and Kovar
Specimens AB 1 through 10 and AB 11 through 20 show that over 80% of the seals were Grade A seals up to the temperature tests. The increased leakage rates after this test could be due to softening of the solder. Vibration tests materially increased leakage in only about 10% of the samples.

2. Class B (adhesive type) seals

a) Kel F film to

1) Aluminum
Specimens BA 1 through 10 show that 80% were Grade A seals up to the temperature test. The one atmosphere

differential on out-leakage at room conditions forced the covers off the remaining 20%.

2) Brass
Specimens BB 1 through 10 showed that 70% were Grade A seals up to the temperature tests. The covers were forced off of 20% on out-leakage at room conditions.

3) Steel
Specimens BS 11 through 20 showed that 80% to 90% were Grade A seals up to the temperature tests. No covers were forced off by the one atmosphere pressure differential. However, nearly all the specimens developed leaks too large to measure after the temperature tests.

The results of the tests on the Kel F film indicate that a combination adhesive, gasket seal might have excellent properties. Since most specimens withstood the two atmosphere differential test, very low bolting pressure might be required to aid the adhesive action.

b) Nitro-Seal to

1) Aluminum
Specimens BA 11 through 20 showed 60% were Grade A seals and 40% Grade D seals after fabrication. All specimens had very large leakage rates after the humidity tests.

2) Brass
Specimens BB 11 through 20 showed 60% to 70% were Grade A seals after fabrication. Most of the specimens developed very large leaks after the humidity tests. Of the 30% of the Grade A seals left prior to the temperature tests, all developed huge leaks or lost their covers.

3) Steel
Specimens BS 21 through 30 showed only 30% of the seals measuring zero leakage on the Gross Leak Meter after fabrication. Almost all had leaks too large to measure after the humidity tests. All covers were off at the end of the temperature tests.

c) Selectron 5208 to

1) Aluminum
Specimens BA 21 through 30 showed 90% Grade A seals after fabrication and after the pressure tests. About 50% of the covers came off after the humidity tests while vibration and temperature tests had no additional effect on the remaining 50% Grade A seals.

2) Steel
Specimens BS 31 through 40 showed 75% Grade A seals after fabrication. Apparently, the adhesive was so weakened by the humidity test that most of the specimens developed leaks too large to measure and lost their covers during the vibration test.

d) Silastic 120 to

1) Aluminum
BA 31 through 40 were for all practical purposes 100% Grade A seals up to the temperature tests. After the temperature tests, only 80% were Grade A seals.

2) Brass
BB 31 through 40 showed that the adhesive action of the Silastic 120 to brass was quite poor since half of the covers came off with a one atmosphere differential across the seal. However, 20% of the specimens had Grade A seals for all measurements.

3) Steel
BS 41 through 50 showed poor sealing qualities although they retained their covers for all tests.

No explanation is known for the difference in results obtained with aluminum as compared to brass and steel. Possibly, the excellence of the aluminum specimens was due to some sort of chemical bonding, for 80% of these specimens were still Grade A seals after the temperature tests.

e) Araldite, Type XI, to brass
Specimens BB 21 through 30 were 100% Grade A seals up to the temperature tests. After the temperature tests, 90% were Grade A seals while 10% were Grade D seals.

f) Kel F dispersion, NW25, to steel
Specimens BS 1 through 10 had leaks too large to measure on all tests.

g) Neo-sil to steel
Specimens BS 51 through 60 showed between 70% and 85% were Grade A seals up to the temperature tests. After the temperature tests, 90% were too large to measure, the remaining 10% very large.

3. Class C (gasket type) seals

a) "O" ring to

1) Aluminum
Specimens CA 1 through 10 showed 100% Grade A seals after fabrication and after pressure tests. The humidity test caused 10% to become Grade B seals. After the temperature test, 90% were still Grade A seals, the remaining being too large to measure. Specimens CA 11 through 15 were also 100% Grade A seals after fabrication and after pressure tests. After the humidity tests, all specimens leaked, keeping relatively constant leakage rates until the temperature tests when the leakage rates increased greatly for 80% of the seals.

2) Brass
Specimens CB 1 through 10 were 100% Grade A seals for all tests up to the temperature tests. About 50% of the Grade A seals remained after the temperature tests. Specimens CB 21 through 25 showed 80% Grade A seals for all tests up to the temperature tests. All specimens developed leaks too large to measure after this test.

3) Steel
Specimens CS 1 through 10 showed only 60% Grade A seals after fabrication. This is not typical of "O" ring seals but might be due to rust causing leakage at the "O" ring surfaces. The specimens were fabricated and assembled for over a year before they were first measured. The humidity tests apparently sealed the leaks for the specimens were 100% Grade A seals after this test and the vibration tests. The temperature tests caused large leaks in all specimens.

Specimens CS 21 through 25 showed 60% Grade A seals for all tests up to the temperature tests. All specimens developed leaks too large to measure after the temperature tests.

The difference in sealing between the "O" rings in the rectangular cross section groove and the "O" rings in the wedge shaped groove was probably due to insufficient compression on the latter. This can sometimes be remedied by a thin coating of vacuum stop cock grease on the "O" ring. The failure after the temperature tests is understandable for "O" rings are not designed to withstand this temperature. Because of the possibility of rusting, brass and aluminum, rather than ordinary steel, are recommended for "O" ring surfaces.

b) Natural rubber gasket to

1) Aluminum
Specimens CA 16 through 26 were 100% Grade A seals for all tests.

2) Brass
Specimens CA 36 through 45 were between 95% and 100% Grade A seals for all tests.

3) Steel
Specimens CS 26 through 35 showed only 15% Grade A seals after fabrication. The humidity test apparently sealed the leaks for the specimens were essentially 100% Grade A seals for the rest of the tests.

Accidentally, the original Specimens CS 26 through 35 were given the temperature tests before measurement at room conditions. Before starting measurements, all the rubber gaskets were removed and replaced with new gaskets. These specimens were assembled only about a week before measurements were started whereas the brass and aluminum specimens were assembled for over a year. This might have some bearing on the much higher leakage rate of Specimens CS 26 through 35.

c) Cork-neoprene gasket to

1) Aluminum
Specimens CA 26 through 35 were all Grade C and D seals after fabrication and pressure tests. The humidity tests reduced the leakage rate somewhat while the temperature tests in nearly all cases increased the leakage rate to a value too large to measure.

Specimens CA 46 through 55 had a more porous type gasket resulting in nearly all the seals being Grade D

for all tests. However, these specimens withstood the temperature tests better than CA 26 through 35 for only 5% of these leaks were too large to measure.

2) Brass
Specimens CB 11 through 20 were nearly all Grade D seals after fabrication. The humidity tests reduced their leakage rates substantially so that after this test 85% of the specimens were Grade C seals. The temperature tests reduced the leakage rates still further so that 25% were Grade A seals after this test.

Specimens CB 46 through 55 were 100% Grade D seals after fabrication. The humidity tests reduced the leakage rates slightly. The temperature tests caused the leakage rates to deviate more from the average than previous tests.

3) Steel
Specimens CS 11 through 20 were mostly Grade C and Grade D seals throughout the tests. The humidity test caused large variations from the average leakage rate and temperature tests increased the leakage rates considerably in most cases.

d) Asbestos fiber compound gasket to

1) Aluminum
Specimens CA 36 through 45 were essentially Grade D seals for all tests. The humidity tests caused a substantial decrease in leakage rates. The leakage rates increased after the temperature tests to a point slightly above the values just after fabrication, indicating that the temperature test was not particularly detrimental.

2) Brass
Specimens CB 26 through 35 were generally Grade D seals except after the vibration tests when almost half became Grade C seals. The humidity tests decreased most of the leakage rates and the vibration tests continued that trend until almost half were just inside Grade C bounds. The temperature tests increased the leakage rate substantially in almost all cases. The high leakage rate of CB 27 after the vibration test was due to temperature testing preceding vibration for this particular specimen. This was done to determine the effects of temperature tests. As a result, temperature tests were conducted last on all other specimens.

3) Steel
Specimens CS 36 through 45 had essentially the same Grade D leakage rates after completion of environmental testing as after fabrication. The humidity and vibration tests both reduced the leakage rate which then increased to its original value after the temperature tests.

e) Steel with

1) Copper sheet gasket
Specimens CS 46 through 55 were borderline Grade A seals in almost all tests. They were not particularly affected by environmental testing. Ring gaskets of certified oxygen free-high conductivity copper wire with ends butt welded and used between smooth, flat surfaces might be expected to give better results.

2) Lead sheet gasket
Specimens CS 56 through 65 remained about 60% Grade A seals for all tests up to the temperature test. The temperature tests increased leakage considerably. The larger out-leakage rates were probably caused by the one atmosphere pressure differential pushing the lead sheet away from the 90° ridge.

4. Class D (lapped type) seals

a) Aluminum to aluminum
Specimens DA 1 through 10 were mostly Grade C seals throughout the tests. The vibration and temperature tests increased the leakage rates slightly.

b) Brass to brass
Specimens DB 1 through 10 had 25% Grade A seals after fabrication, the percentage gradually diminishing on each test. No Grade A seals were left after the temperature tests. There were no Grade D seals after any tests.

c) Steel to steel
Specimens DS 1 through 10 were predominantly Grade C seals throughout the tests. The leakage rates decreased slightly after the vibration tests.

C. Accuracy of the Data

1. Measurements on High Sensitivity Leak Meter

The absolute accuracy of the measurements made on this leak meter is primarily dependent on the accuracy of the calibrated leaks and the reproducibility of the leak meter on duplicate runs.

As can be seen from the Calibration Curves, Figures 14 and 15, nine calibrated leaks were used to calibrate the instrument. The eight smaller leaks, calibrated for air, were purchased from one manufacturer, while the largest leak which was calibrated for helium was obtained from another manufacturer. The latter leak was converted to air leakage assuming viscous flow as stated in the section on calibration.

According to the manufacturer, the accuracy of calibration depends on the method of calibration and the type of gas flow through the calibrated leaks. The calibration accuracy of the nine calibrated leaks as listed by the manufacturers is as follows:

Calibrated leaks ranging from	Accuracy
19 to 470 std. cc. of air/yr.	-0, + 100%
1450 to 36,200 std. cc. of air/yr.	-5, + 5% at 760 mm.
70,100 std. cc. of air/yr.	-5, + 5%.

Reproducibility of measurements on duplicate runs with calibrated leaks has always been within ± 20% when the palladium was not desensitized by oxygen. Up to 10% of this variation could be caused by changing atmospheric pressure affecting the flow rate. Another probable cause of variation is the extreme sensitivity of the smaller calibrated leaks to moisture, dust particles and temperature changes.

Assuming the maximum possible error, the estimated accuracy of measurements made with the High Sensitivity Leak Meter is as follows:

Leakage rate range	Accuracy
1 to 1,000 std. cc. of air/yr.	-20, + 120%
1,000 to 100,000 std. cc. of air/yr.	-25, + 25%

(This applied to total leakage rate. Leakage rates/inch of seal can be converted to total leakage rates by multiplying by the appropriate length of seal listed in Test Specimens, Details of Fabrication.)

2. Measurements on the Gross Leak Meter

The absolute accuracy of measurements made with this leak meter also depends on the range of measurements. The accuracy of measurements of the fastest leakage rates is limited by the difficulty in accurate timing of the short interval. For the smaller leaks, the accuracy is dependent on reproducibility of measurements on duplicate runs.

The stopwatch can be stopped consistently to within ± 1/4 second. The water plug moves 10 cm. in 1.9 sec. for a leak of 3,000,000 std. cc. of air/yr. Timing would cause an error of less than ± 15% here. Of course, a 30 cm. run could be made to minimize this timing error, should it be desired to measure these very large leaks more accurately.

The decrease in reproducibility for the smaller leaks is primarily caused by the resistive forces of surface tension and the inertia of the water plug. The various validation and calibration runs made with the calibrated leaks show how these errors increase with decreasing leakage rate.

The estimated accuracy of measurements made with the Gross Leak Meter (also Portable Leak Meter) is as follows:

Leakage rate range (in std. cc. of air/yr.)	Accuracy
1,000,000 - 3,000,000	± 15%
70,000 - 1,000,000	± 10%
25,000 - 70,000	± 20%
15,000 - 25,000	± 30%
5,000 - 15,000	± 50%

(Leakage rates/inch of seal can be converted to total leakage rates by multiplying by the corresponding test specimen length of seal.)

The quantitative accuracy of the 2% of the measurements between O* and 1000* std. cc. of air/yr./inch of seal is unknown. These measurements were made on the Gross Leak Meter before the High Sensitivity Leak Meter was perfected and were considered below the recommended lower limit of the instrument. The policy adopted at that time to speed measurements was to accept these measurements as final if substitution of a zero leakage rate would not change the average (arithmetical at that time) more than 10%. For example, assume nine of the specimens had a leakage rate of 10,000 std. cc. of air/yr./inch of seal and the tenth had some unknown leakage rate smaller than 1,000 std. cc. of air/yr./inch of seal as measured on the Gross Leak Meter. Substitution of a zero leakage rate for the tenth specimen would not change the arithmetical average by more than one part in 90 or slightly over 1%. It was, therefore, unnecessary to know the exact leakage rate value between O* and 1000* std. cc. of air/yr./inch of seal where it would not appreciably affect the average. Accordingly, the whole group was allowed to proceed with the environmental testing rather than holding it back for remeasurement on the High Sensitivity Leak Meter when it was perfected.

Adoption of the grading system of averaging presents another difficulty which did not arise with the arithmetic averaging method. It is not known whether specimens with leakage rates between O* and 100* std. cc. of air/yr./inch of seal were Grade A, B, or C seals. Some of these could be Grade C seals because leakage rate measurements might tend to be low on measurements made below the lower limit of the Gross Leak Meter. For the 1-1/2% of the measurements between O* and 100* std. cc. of air/yr./inch of seal, measured on the Gross Leak Meter, these specimens were classified as Grade B seals.

D. Leakage Rate Measurements of Sealed Electronic Components

The following components submitted by Wright Air Development Center were measured for out-leakage as described in Analysis of Non-Destructive Testing. The condition of the component is added as an aid in evaluation since the previous history of these components is not known.

Sample No.	Leakage Rate (in std. cc. of air/yr.)	Condition of Component
1	0	new
2	0	new
3	0	new
4	1,400	used
5	280	new - 2 seals look suspicious
6	0	new
7	0	new
8	0	new
9	0	new
10	0	new
11	0	new
12	4,000	new - looks identical to rest
13	0	new
14	0	new
15	0	new
16	0	new
17	31	new
18	210	new
19	7,900	used

Sample No.	Leakage Rate (in std. cc. of air/yr.)	Condition of Component
20	20,000*	used
21	9,000*	used
22	16,000*	used
23	0	used - badly rusted
24	0	new
25	0	new
26	6,700	new
27	5,800	new
28	3,300	new
29	9,700	new
30	2,300,000*	new
31	0	new
32	29,000*	new
33	0	new
34	0	new
35	0	new
36	0	new
37	0	new
38	0*	new
39	0*	new
40	0*	new
41	0*	new
42	0*	new
43	0*	new

* = measured on the Gross Leak Meter

E. Visual Correlation

After the leakage rate measurements were completed, an attempt was made to determine whether the specimens which leaked could be picked out by visual inspection from those which did not. This was not possible for the Class B, C, and D specimens for the sealing surfaces are not visible. However, with the Class A, metal to metal fusion seals, it was possible in almost all cases to pick out which seals did not leak. One cannot with the same assurance pick out which seals leak - he can only pick out which seals are suspicious. What appears to be a leak at the surface might be sealed just below the surface of the seal.

Figure 36 shows two specimens, AAS 8 on the left, which showed no leakage, and AAS 9 which did leak. Both specimens were cleaned in acid after completion of the measurements to remove the rust and to accentuate any irregularities in the seal. A very noticeable gap can be seen in the silver solder joint on the specimen on the right. This gap was barely visible before acid cleaning. A thin crack like this is difficult to detect because it blends in with the thin solder line along the insert cover. This type of solder joint is not recommended for this reason.

An ideal example of smooth fillet type solder joints is shown in Figure 37. Both the aluminum cover and the specimen tube were sealed with joints of this type. Both can be examined in less than a second and pronounced leak tight without any possible doubt. None of the aluminum specimens with fillet type joints leaked.

Another example of smooth fillet type joints is shown in the top and side view of AAS 51 in Figure 38. The top two seals are both smooth silver solder fillets while the side view shows the smooth soft solder fillet between the case and the bottom cover. No specimens of this type leaked.

Full, smooth solder joints are recommended wherever possible because of the ease of inspection.

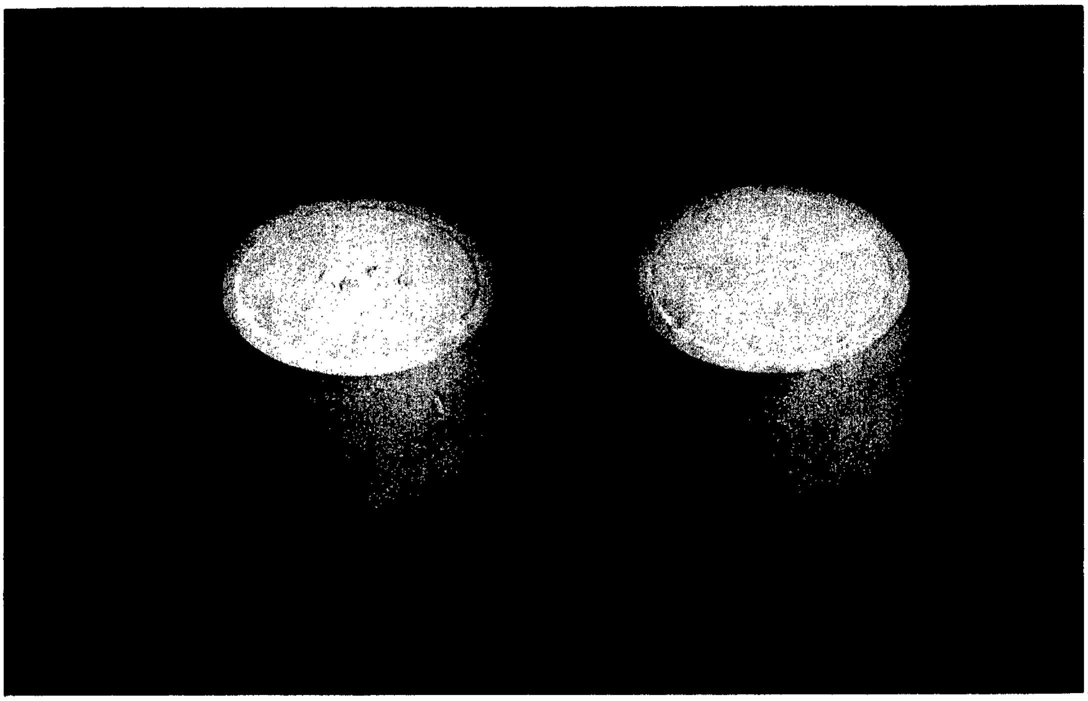


Figure 36. Comparison of Two Silver Soldered Steel-to-Steel Seals. A slight gap is visible at about nine o'clock on the specimen at the right.

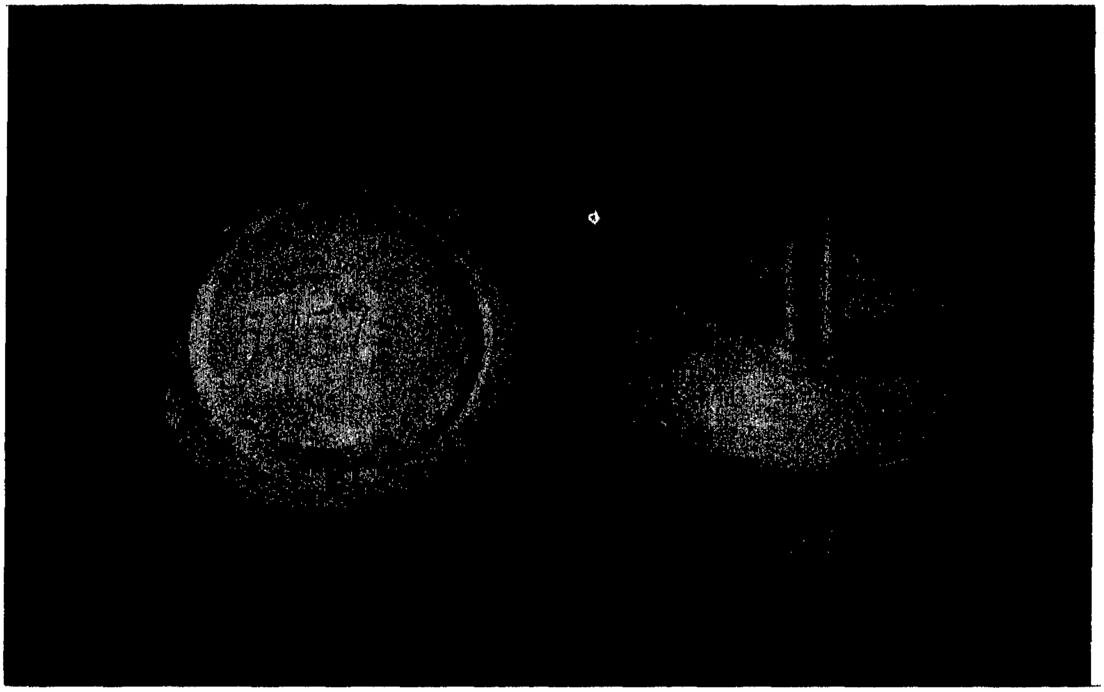


Figure 37. Aluminum-to-Aluminum Seal With Smooth Fillet Type Solder Joints.

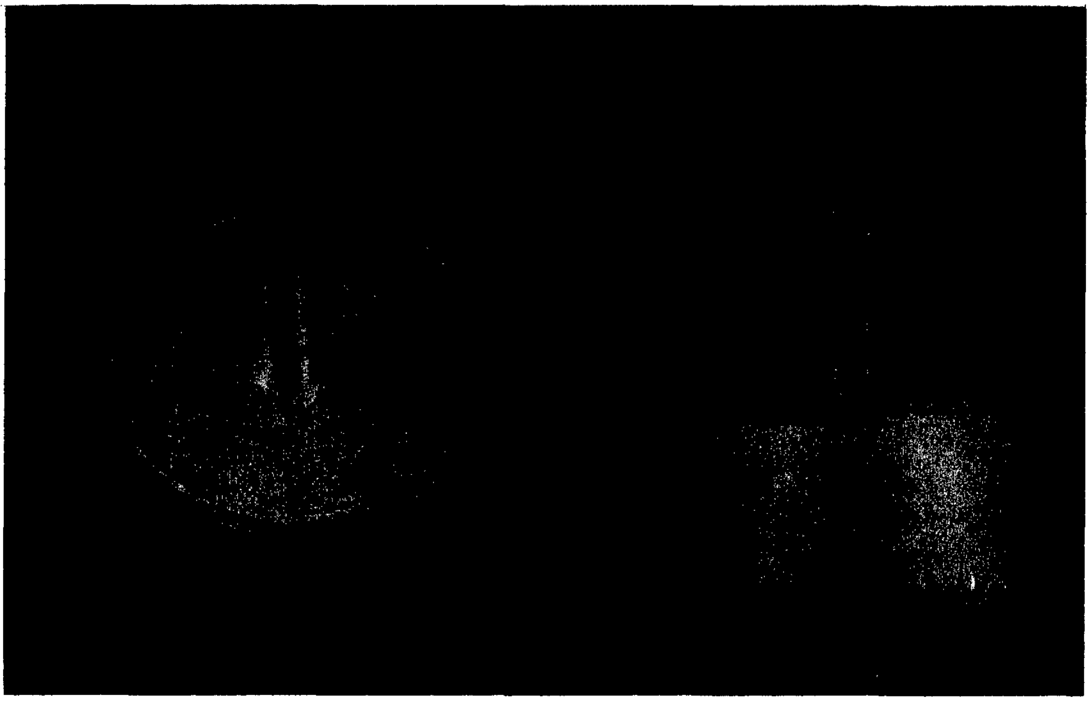


Figure 38. Steel-to-Steel Seal With Smooth Fillet Type Solder Joints.

APPENDIX

The section which follows consists of the following tables:

Table No. 1 - Leakage Rates of Various Seals

Table No. 2 - Performance Rating of Specimens

Table No. 3 - Specimen Performance Chart

Table No. 4 - Trade Names and Suppliers

In Table No. 1, the leakage rates per inch of seal for each of the 449 fabricated test specimens are reported. There are ten measurements for each specimen, comprising in- and out-leakage rates for each stage of the environmental exposure cycle. The following is an explanation of the symbols used in Table No. 1.

<	= less than
*	= measured on Gross Leak Meter
X	= too large a leak for Gross Leak Meter
off--	= cover off (adhesive, Class B seals only).

Table No. 2 represents a system of grading the quality of the seals and averaging the results. The significance of the various grades is shown below:

Grade	Leakage Rate (in std. cc. of air/yr./inch of seal)
A	0-1*
B	1-100*
C	100-10,000*
D	10,000 and higher
* Upper limit not included.	

Each specimen was graded according to its in- and out-leakage rate for each environmental test. The percentage in each grade for each environmental test was computed after totaling the number in each grade for each test. For example, Specimens AAS 1 through 10 had in- and out-leakage rates after temperature tests which classified them as 18 Grade A and 2 Grade D seals. Thus, 90% were Grade A seals after this

test while 10% were Grade D seals. These percentages are incorporated in Table No. 2, the Performance Rating of Specimens. Besides listing the percentage in each grade for each environmental test, the table also gives the average for all the environmental tests for each specimen type. For example, for Specimens BS 11 through 20, 90% were Grade A seals at room conditions, 90% after pressure exposure, 80% after humidity exposure, 80% after vibration exposure, and 10% after temperature exposure. Thus, the overall average rating was

$$\frac{90 + 90 + 80 + 80 + 10}{5} = 70\%$$

These average ratings, listed in the last column of Table No. 2, are presented graphically in the "Specimen Performance Charts" (Table No. 3).

Table No. 4 is self-explanatory.

TABLE NO. 1

LEAKAGE RATES OF VARIOUS SEALS

(in standard cc. of air/yr./inch of seal)

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
AAA 1	0	0	0	0	0	0	0	0	0	0
AAA 2	0	0	0	0	0	0	0	0	0	0
AAA 3	0	0	0	0	0	0	0	0	0	0
AAA 4	0	0	0	0	0	0	0	0	0	0
AAA 5	0	0	0	0	0	0	0	0	0	0
AAA 6	0	0	0	0	0	0	0	0	0	0
AAA 7	0	0	0	0	<1	0	0	0	0	0
AAA 8	0	0	0	0	0	0	0	0	0	0
AAA 9	0	0	0	0	0	0	0	0	0	0
AAA 10	0	0	0	0	0	0	0	0	0	0
AAA 1 - 10 are aluminum soldered, aluminum to aluminum specimens.										
AAB 1	0	0	0	0	0	0	0	0	0	0
AAB 2	0	0	0	0	0	0	0	0	0	0
AAB 3	0	0	0	0	0	0	0	0	0	0
AAB 4	0	0	0	0	0	0	0	0	0	0
AAB 5	0	0	0	0	0	0	0	0	0	0
AAB 6	0	0	0	0	0	0	0	0	0	0
AAB 7	0	0	0	0	0	0	0	0	0	0
AAB 8	0	0	0	0	0	0	0	0	0	0
AAB 9	0	0	0	0	0	0	0	0	0	0
AAB 10	0	0	0	0	0	0	0	0	0	0
AAB 1 - 10 are silver soldered, brass to brass specimens.										
AAB 11	0	0	0	0	0	0	0	0	15	10
AAB 12	0	0	0	0	0	0	0	0	0	0
AAB 13	0	0	0	0	0	0	0	0	0	0
AAB 14	0	0	0	0	0	0	0	0	22,000	18,000
AAB 15	0	0	0	0	0	0	0	0	0	0

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
AAB 16	0	0	0	0	0	0	0	0	0	0
AAB 17	0	0	0	0	0	0	0	0	0	0
AAB 18	0	0	0	0	0	0	0	0	0	0
AAB 19	0	0	0	0	0	0	0	0	0	0
AAB 20	0	0	0	0	0	0	0	0	X	X
AAB 11 - 20 are soft soldered, brass to brass specimens.										
AAS 1	0	0	0	0	0	0	0	0	0	0
AAS 2	0	0	0	0	0	0	0	0	0	0
AAS 3	0	0	0	0	0	0	0	0	0	0
AAS 4	0	0	0	0	0	0	0	0	0	0
AAS 5	0	0	0	0	0	0	0	0	0	0
AAS 6	0	0	0	0	0	0	0	0	0	0
AAS 7	0	0	0	0	0	0	0	0	0	0
AAS 8	0	0	0	0	<1	0	0	0	0	0
AAS 9	18	16	20	16	7,700	8,100	12,000	12,000	180,000*	55,000*
AAS 10	0	0	0	0	0	0	0	0	0	0
AAS 1 - 10 are silver soldered, steel to steel specimens with insert covers.										
AAS 11	0	0	0	0	0	0	0	0	0	0
AAS 12	0	0	0	0	0	0	0	0	0	0
AAS 13	0	0	0	0	0	0	0	0	0	0
AAS 14	0	0	0	0	0	0	0	0	0	0
AAS 15	0	0	0	0	0	0	0	0	0	0
AAS 16	0	0	0	0	0	0	0	0	0	0
AAS 17	0	0	0	0	0	0	0	0	0	0
AAS 18	0	0	0	0	0	0	0	0	0	0
AAS 19	0	0	0	0	0	0	0	0	0	0
AAS 20	0	0	0	0	0	0	0	0	0	0
AAS 11 - 20 are silver soldered, steel to steel specimens with overhang covers.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
AAS 21	<1	0	0	0	0	0	<1	0	<1	0
AAS 22	8	7	9	8	<1	<1	1	0	24	7
AAS 23	5	4	4	3	6	3	7	1	20	15
AAS 24	X	X	X	X	21,000	76,000*	64,000*	43,000*	366,000*	233,000*
AAS 25	0	0	0	0	0	0	0	0	12	8
AAS 26	11	10	11	10	10	8	11	23	85	78
AAS 27	<1	<1	0	0	<1	0	0	0	1,700	1,1000
AAS 28	0	0	0	0	0	0	0	0	0	<1
AAS 29	19,000	20,000	20,000	20,000	12,000	12,000	13,000	15,000	233,000*	52,000*
AAS 30	6	5	4	3	2	1	2	4	9	7
AAS 21 - 30 are gas welded, steel to steel specimens.										
AAS 31	400,000*	350,000*	400,000*	410,000*	280,000*	250,000*	280,000*	240,000*	500,000*	460,000*
AAS 32	540,000*	480,000*	500,000*	540,000*	290,000*	250,000*	280,000*	250,000*	340,000*	330,000*
AAS 33	1,200,000*	990,000*	1,000,000*	980,000*	140,000*	110,000*	130,000*	120,000*	270,000*	250,000*
AAS 34	X	X	X	X	2,400,000*	4,000,000*	2,600,000*	2,600,000*	X	X
AAS 35	10,000*	21,000*	17,000*	17,000*	7,900*	9,300*	8,300*	9,100*	44,000*	49,000*
AAS 36	12,000*	X	26,000*	23,000*	29,000*	30,000*	26,000*	35,000*	120,000*	110,000*
AAS 37	42,000*	190,000*	260,000*	250,000*	230,000*	220,000*	230,000*	170,000*	370,000*	340,000*
AAS 38	0*	0*	0*	0*	0*	110*	0*	0*	0*	4,700*
AAS 39	1,100,000*	1,200,000*	1,000,000*	1,100,000*	990,000*	990,000*	1,000,000*	990,000*	1,200,000*	1,200,000*
AAS 40	4,300*	11,000*	9,000*	8,700*	980*	7,500*	18,000*	7,100*	53,000*	55,000*
AAS 41	5,500*	19,000*	15,000*	15,000*	6,000*	6,500*	5,660*	4,300*	1,100,000*	1,100,000*
AAS 42	33,000*	280,000*	280,000*	280,000*	250,000*	230,000*	230,000*	240,000*	700,000*	740,000*
AAS 43	4,600*	6,800*	0*	0*	0*	730*	0*	410*	9,700*	15,000*
AAS 44	22,000*	46,000*	63,000*	60,000*	15,000*	12,000*	14,000*	19,000*	83,000*	79,000*
AAS 31 - 44 are electric welded, steel to steel specimens.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
AAS 45	0	0	0	0	0	0	0	0	0	0
AAS 46	0	0	0	0	0	0	0	0	0	0
AAS 47	0	0	0	0	0	0	0	0	0	0
AAS 48	0	0	0	0	0	0	0	0	0	0
AAS 49	0	0	0	0	0	0	0	0	0	0
AAS 50	0	0	0	0	0	0	0	0	0	0
AAS 51	0	0	0	0	0	0	0	0	0	0
AAS 52	0	0	0	0	0	0	0	0	0	0
AAS 53	0	0	0	0	0	0	0	0	0	0
AAS 54	0	0	0	0	0	0	0	0	0	0
AAS 45 - 54 are soft soldered, steel to steel specimens.										
AB 1	0	0	0	0	0	0	0	0	<1	<1
AB 2	0	0	0	0	0	0	0	0	0	0
AB 3	0	0	0	0	0	0	0	0	0	0
AB 4	0	0	0	0	0	0	6	0	120	110
AB 5	0	0	0	0	<1	2	<1	3	39	52
AB 6	0	0	0	0	0	0	0	0	0	0
AB 7	1,600	2,200	1,500	2,000	85	90	88	180	370	460
AB 8	0	0	0	0	0	0	0	0	0	0
AB 9	0	0	0	0	0	0	0	0	0	0
AB 10	0	0	0	0	0	0	0	0	0	0
AB 1 - 10 are glass to steel seals, soft soldered to a Marion meter case.										
AB 11	0	0	0	0	0	0	0	0	110	54
AB 12	0	0	0	0	0	0	0	0	0	0
AB 13	1	4	29	0	76	30	54	45	240	200
AB 14	0	0	0	0	5,000	4,000	790	0	21,000	23,000
AB 15	11,000	6,900	0	0	340	5	2	0	37	11

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
AB 16	0	0	0	0	0	0	0	0	0	0
AB 17	0	0	0	0	0	0	0	39,000	40,000	43,000
AB 18	0	0	0	0	0	0	0	0	0	0
AB 19	<1	0	0	0	0	0	0	0	0	0
AB 20	0	0	0	0	0	0	0	0	0	<1
AB 11 - 20 are glass to Kovar seals, soft soldered to a Marion meter case.										
BA 1	0	0	0	0	0	0	0	0	0	0
BA 2	0	0	0	0	0	0	0	0	0	0
BA 3	34,000*	off	-	-	-	-	-	-	-	-
BA 4	13,000*	off	-	-	-	-	-	-	-	-
BA 5	0	0	0	0	0	0	0	0	0	0
BA 6	0	0	0	0	0	<1	0	0	X	X
BA 7	0	0	0	0	0	0	0	0	0	0
BA 8	0	0	0	0	<1	0	0	0	0	0
BA 9	0	0	0	0	0	0	0	0	0	0
BA 10	0	0	0	0	0	0	0	0	0	0
BA 1 - 10 use Kel F film, Type B, as adhesive between aluminum and aluminum.										
BA 11	22,000	78,000*	25,000	1,200,000*	X	X	X	X	off	-
BA 12	0	0	0	0	X	off	-	-	-	-
BA 13	0	0	0	0	690,000*	1,400,000*	1,200,000*	X	off	-
BA 14	0	0	0	0	X	X	X	off	-	-
BA 15	0	0	0	0	X	X	X	off	-	-
BA 16	0	0	0	0	X	off	-	-	-	-
BA 17	X	X	X	X	X	X	X	X	off	-
BA 18	890,000*	840,000*	940,000*	1,100,000*	X	X	X	X	off	-
BA 19	15,000	16,000	15,000	16,000	X	X	X	X	off	-
BA 20	0	0	0	0	X	off	-	-	-	-
BA 11 - 20 use Nitroseal as adhesive between aluminum and aluminum.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
BA 21	0	0	0	0	off	-	-	-	-	-
BA 22	7,800*	12,000	7,100	4,900	71	off	-	-	-	-
BA 23	0	0	0	0	0	0	0	0	0	0
BA 24	0	0	0	0	320,000*	0	0	0	0	0
BA 25	0	0	0	0	0	0	0	0	0	0
BA 26	0	0	0	0	0	off	-	-	-	-
BA 27	0	0	0	0	0	0	0	0	0	0
BA 28	0	0	0	0	0	0	0	0	0	0
BA 29	0	0	0	0	off	-	-	-	-	-
BA 30	0	0	0	0	X	off	-	-	-	-
BA 21 - 30 use Selectron 5208 as adhesive between aluminum and aluminum.										
BA 31	0	0	0	0	0	0	0	0	0	0
BA 32	0	0	0	0	0	0	0	0	0	0
BA 33	0	0	0	0	0	0	0	0	<1	0
BA 34	0	0	0	0	0	0	0	0	0	0
BA 35	0	0	0	0	0	0	0	0	660	490
BA 36	0	0	0	0	0	0	0	0	0	0
BA 37	0	0	0	0	2	2	0	0	25	54
BA 38	0	0	0	0	0	0	0	0	0	0
BA 39	0	0	0	0	0	0	0	0	<1	0
BA 40	0	0	0	0	0	0	0	0	0	0
BA 31 - 40 use Silastic 120 as adhesive between aluminum and aluminum.										
BB 1	0	0	0	0	0	0	0	0	0	0
BB 2	14,000*	off	-	-	-	-	-	-	-	-
BB 3	0	0	0	0	0	0	0	0	0	0
BB 4	9,700*	off	-	-	-	-	-	-	-	-
BB 5	0	0	0	0	0	0	0	0	0	0

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
BB 6	0	0	0	0	0	0	0	0	0	0
BB 7	0	0	0	0	0	0	0	0	0	0
BB 8	0	0	0	0	0	0	0	0	0	0
BB 9	22,000*	55,000*	81,000*	59,000*	22,000	94,000*	1,100,000*	940,000*	0	0
BB 10	0	0	0	0	0	0	0	0	0	0
BB 1 - 10 use Kel F film, Type B, as adhesive between brass and brass.										
BB 11	X	X	X	X	X	off	-	-	-	-
BB 12	0	0	0	0	470,000*	800,000*	off	-	-	-
BB 13	7	<1	7	5	670,000*	760,000*	off	-	-	-
BB 14	270,000*	X	X	X	X	off	-	-	-	-
BB 15	2	<1	2	1	off	-	-	-	-	-
BB 16	0	0	0	0	730,000*	120,000*	1,000,000*	540,000*	off	-
BB 17	0	0	0	0	19	13	45	36	off	-
BB 18	0	0	0	0	0	0	0	0	off	-
BB 19	0	0	0	0	0	0	0	0	960,000*	600,000*
BB 20	0	0	0	0	0	0	0	0	off	-
BB 11 - 20 use Nitroseal as adhesive between brass and brass.										
BB 21	0	0	0	0	0	0	0	0	0	0
BB 22	0	0	0	0	0	0	0	0	0	0
BB 23	0	0	0	0	0	0	0	0	0	0
BB 24	0	0	0	0	0	0	0	0	0	0
BB 25	0	0	0	0	<1	0	0	0	430,000*	120,000*
BB 26	0	0	0	0	0	0	0	0	0	0
BB 27	0	0	0	0	0	0	0	0	0	0
BB 28	0	0	0	0	0	0	0	0	0	0
BB 29	0	0	0	0	0	0	0	0	0	0
BB 30	0	0	0	0	0	0	0	0	0	0
BB 21 - 30 use Araldite, Type XI, as adhesive between brass and brass.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
BB 31	610,000*	X	off	-	-	-	-	-	-	-
BB 32	0	off	-	-	-	-	-	-	-	-
BB 33	0	off	-	-	-	-	-	-	-	-
BB 34	0	0	0	0	0	0	0	0	0	0
BB 35	0	5	0	0	0	0	0	0	0	0
BB 36	12,000	10	15	17	36	500,000*	31	1,200,000*	0	0
BB 37	11,000	off	-	-	-	-	-	-	-	-
BB 38	0	off	-	-	-	-	-	-	-	-
BB 39	0	0	0	0	0	0	0	0	0	0
BB 40	X	off	-	-	-	-	-	-	-	-
BB 31 - 40 use Silastic 120 as adhesive between brass and brass.										
BS 1	X	X	X	X	X	X	X	X	X	X
BS 2	X	X	X	X	X	X	X	X	X	X
BS 3	X	X	off	-	-	-	-	-	-	-
BS 4	X	X	X	X	X	X	off	-	-	-
BS 5	X	X	X	X	X	X	X	X	X	X
BS 6	X	X	X	X	X	X	X	X	X	X
BS 7	X	X	X	X	X	X	X	X	X	X
BS 8	X	X	X	X	X	X	X	X	X	X
BS 9	X	X	X	X	X	X	X	X	X	X
BS 10	X	off	-	-	-	-	-	-	-	-
BS 1 - 10 use Kel F dispersion, NW 25, as adhesive between steel and steel.										
BS 11	30	24	27	26	2,700	3,600	5,200	5,700	X	X
BS 12	0	0	0	0	0	0	0	0	0	9,000*
BS 13	0	0	0	0	0	0	0	0	X	X
BS 14	0	0	0	0	0	0	0	0	X	X
BS 15	0	0	0	0	0	0	0	0	X	X

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
BS 16	0	0	0	0	<1	0	0	0	X	X
BS 17	0	0	0	0	0	0	0	0	X	X
BS 18	0	0	0	0	0	0	0	0	X	X
BS 19	0	0	0	0	3	3	130	120	X	X
BS 20	0	0	0	0	0	0	0	0	6	0
BS 11 - 20 use Kel F film, Type B, as adhesive between steel and steel.										
BS 21	44,000*	42,000*	29,000*	42,000*	X	X	X	X	off	-
BS 22	16,000*	16,000*	12,000*	18,000*	X	X	X	X	off	-
BS 23	62,000*	55,000*	40,000*	58,000*	X	X	X	X	off	-
BS 24	0*	0*	0*	0*	X	X	off	-	-	-
BS 25	0*	0*	1,500*	0*	X	X	X	X	off	-
BS 26	4,500*	4,000*	3,600*	5,600*	X	X	X	X	off	-
BS 27	0*	0*	0*	0*	120,000*	200,000*	X	X	off	-
BS 28	22,000*	23,000*	16,000*	28,000*	X	X	X	X	off	-
BS 29	48,000*	48,000*	31,000*	50,000*	X	X	X	X	off	-
BS 30	10,000*	12,000*	8,700*	18,000*	X	X	X	X	off	-
BS 21 - 30 use Nitroseal as adhesive between steel and steel.										
BS 31	0	0	0	0	0	X	off	-	-	-
BS 32	44	41	41	42	51,000*	13	off	-	-	-
BS 33	0	0	0	0	0	0	900,000*	X	X	X
BS 34	4	3	3	2	10,000	X	off	-	-	-
BS 35	0	0	0	0	0	X	off	-	-	-
BS 36	0	0	0	0	0	X	off	-	-	-
BS 37	0	0	0	0	0	X	off	-	-	-
BS 38	0	0	0	0	0	X	off	-	-	-
BS 39	0	0	0	0	0	0	0	0	0	X
BS 40	0	X	810,000*	X	X	X	off	-	-	-
BS 31 - 40 use Selectron 5208 as adhesive between steel and steel.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
BS 41	14,000*	11,000*	130,000*	140,000*	130,000*	120,000*	120,000*	150,000*	140.000*	180,000*
BS 42	0*	0*	0*	27,300*	0*	16,000*	0*	11,000*	0*	10,000*
BS 43	5,600*	91,000*	23,000*	120,000*	5,300*	31,000*	17,000*	58,000*	22,000*	35,000*
BS 44	3,800*	350,000*	34,000*	1,500,000*	10,000*	X	27,000*	810,000*	59,000*	810,000*
BS 45	0	2,200,000*	6,900*	X	6,600*	X	11,000*	1,300,000*	0*	1,000,000*
BS 46	40,000*	2,200,000*	1,100,000*	3,000,000*	X	X	1,300,000*	2,200,000*	1,800,000*	2,200,000*
BS 47	14,000*	520,000*	84,000*	2,200,000*	230,000*	X	250,000*	1,500,000*	260,000*	1,300,000*
BS 48	0*	18,000*	6,800*	81,000*	6,300*	100,000*	11,000*	110,000*	14,000*	140,000*
BS 49	40,000*	1,800,000*	1,100,000*	X	X	X	1,300,000*	1,500,000*	1,800,000*	2,200,000*
BS 50	2,800*	52,000*	22,000*	810,000*	31,000*	X	43,000*	390,000*	59,000*	180,000*
BS 41 - 50 use Silastic 120 as adhesive between steel and steel.										
BS 51	0	0	0	0	0	0	0	0	560,000*	380,000*
BS 52	0	<1	0	0	0	0	0	<1	X	X
BS 53	0	0	0	0	0	0	0	0	X	X
BS 54	0	0	0	0	0	0	0	0	X	X
BS 55	0	0	0	0	0	0	0	0	X	X
BS 56	0	3	3	4	4	2	32	38	X	X
BS 57	10	8	11	7	6	8	14	21	X	X
BS 58	0	0	0	0	7	6	30	31	X	X
BS 59	0	0	0	0	0	0	0	0	X	X
BS 60	0	0	0	0	0	0	0	0	X	X
BS 51 - 60 have a Neo-sil, neoprene-silicone to steel seal soft soldered to a Marion meter case.										
CA 1	0	0	0	0	0	0	0	0	0	0
CA 2	0	0	0	0	0	0	0	0	0	0
CA 3	0	0	0	0	0	0	0	0	0	0
CA 4	0	0	0	0	0	0	0	0	0	0
CA 5	0	0	0	0	0	0	0	0	0	0

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
CA 6	0	0	0	0	0	0	0	0	0	0
CA 7	0	0	0	0	0	0	0	0	X	X
CA 8	0	0	0	0	0	0	0	0	0	0
CA 9	0	0	0	0	0	0	0	0	0	0
CA 10	0	0	0	0	11	12	12	10	0	0
CA 1-10 have an "O" ring seal between aluminum and aluminum in a rectangular cross sectional groove.										
CA 11	0	0	0	0	210	260	170	99	78,000*	X
CA 12	0	0	0	0	4,000	4,100	4,600	5,100	X	X
CA 13	0	0	0	0	36	21	36	36	0	0
CA 14	0	0	0	0	4,400	5,800	5,300	5,200	X	X
CA 15	<1	<1	<1	0	12,000	16,000	13,000	13,000	470,000*	X
CA 11 - 15 have an "O" ring seal between aluminum and aluminum in a wedge shaped groove.										
CA 16	0	0	0	0	0	0	0	0	0	0
CA 17	0	0	0	0	0	0	0	0	0	0
CA 18	0	0	0	0	0	0	0	0	0	0
CA 19	0	0	0	0	0	0	0	0	0	0
CA 20	0	0	0	0	0	0	0	0	0	0
CA 21	0	0	0	0	0	0	0	0	0	0
CA 22	0	0	0	0	0	0	0	0	0	0
CA 23	0	0	0	0	0	0	0	0	0	0
CA 24	0	0	0	0	0	0	0	0	0	0
CA 25	0	0	0	0	0	0	0	0	0	0
CA 16 - 25 have a gasket seal of natural rubber in a rectangular cross sectioned groove between aluminum and aluminum.										
CA 26	55,000*	54,000*	30,000*	27,000*	5,600*	6,000*	5,900*	9,400*	X	X
CA 27	19,000*	26,000*	9,200*	6,800*	3,700*	5,200*	4,600*	7,300*	X	X
CA 28	20,000*	18,000*	9,800*	11,000*	3,400*	2,700*	3,800*	6,400*	X	X
CA 29	24,000*	22,000*	12,000*	14,000*	3,200*	3,200*	4,400*	6,900*	X	X
CA 30	19,000*	18,000*	9,800*	11,000*	4,400*	5,600*	6,600*	12,000*	X	X

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
CA 31	13,000*	15,000*	7,400*	8,500*	3,900*	3,500*	5,200*	8,500*	X	X
CA 32	19,000*	21,000*	11,000*	11,000*	3,800*	5,200*	7,000*	8,400*	X	X
CA 33	5,300*	6,600*	3,200*	3,400*	0*	1,300*	3,000*	2,600*	2,600,000*	X
CA 34	6,700*	8,400*	4,500*	4,200*	0*	840*	3,300*	3,500*	3,300,000*	X
CA 35	11,000*	14,000*	6,800*	6,800*	5,600*	2,900*	9,300*	12,000*	X	X
CA 26 - 35 have a gasket seal of cork-neoprene composition (Armstrong DC 100) rectangular cross sectioned groove between aluminum and aluminum.										
CA 36	140,000*	140,000*	160,000*	150,000*	17,000*	85,000*	90,000*	87,000*	180,000*	170,000*
CA 37	78,000*	76,000*	87,000*	77,000*	8,900*	37,000*	38,000*	39,000*	94,000*	91,000*
CA 38	170,000*	180,000*	190,000*	180,000*	110,000*	110,000*	110,000*	110,000*	260,000*	250,000*
CA 39	120,000*	120,000*	140,000*	130,000*	71,000*	71,000*	70,000*	72,000*	160,000*	160,000*
CA 40	220,000*	220,000*	250,000*	230,000*	73,000*	150,000*	150,000*	160,000*	280,000*	260,000*
CA 41	120,000*	120,000*	130,000*	120,000*	66,000*	65,000*	65,000*	64,000*	130,000*	120,000*
CA 42	110,000*	110,000*	120,000*	110,000*	72,000*	65,000*	65,000*	65,000*	150,000*	150,000*
CA 43	100,000*	98,000*	110,000*	100,000*	59,000*	58,000*	60,000*	61,000*	91,000*	88,000*
CA 44	46,000*	45,000*	53,000*	46,000*	27,000*	23,000*	22,000*	23,000*	53,000*	52,000*
CA 45	320,000*	310,000*	350,000*	320,000*	210,000*	190,000*	190,000*	190,000*	340,000*	330,000*
CA 36 - 45 have a gasket seal of asbestos fiber compound in a rectangular cross sectional groove between aluminum and aluminum.										
CA 46	90,000*	90,000*	100,000*	98,000*	22,000*	20,000*	17,000*	22,000*	760,000*	220,000*
CA 47	110,000*	110,000*	130,000*	120,000*	41,000*	39,000*	37,000*	41,000*	2,600,000*	720,000*
CA 48	79,000*	76,000*	85,000*	86,000*	20,000*	18,000*	17,000*	19,000*	150,000*	77,000*
CA 49	98,000*	98,000*	110,000*	110,000*	32,000*	33,000*	31,000*	32,000*	250,000*	120,000*
CA 50	68,000*	70,000*	71,000*	76,000*	26,000*	26,000*	25,000*	28,000*	1,400,000*	650,000*
CA 51	53,000*	55,000*	47,000*	57,000*	18,000*	17,000*	16,000*	18,000*	1,600,000*	420,000*
CA 52	110,000*	110,000*	120,000*	120,000*	39,000*	37,000*	39,000*	38,000*	1,400,000*	260,000*
CA 53	220,000*	220,000*	240,000*	220,000*	7,800*	5,500*	6,300*	6,400*	14,000*	13,000*
CA 54	78,000*	83,000*	87,000*	87,000*	26,000*	26,000*	26,000*	28,000*	870,000*	150,000*
CA 55	92,000*	96,000*	100,000*	100,000*	40,000*	40,000*	38,000*	41,000*	X	2,600,000*
CA 46 - 55 have a gasket seal of cork-neoprene composition (Armstrong DC 167) in a rectangular cross sectioned groove between aluminum and aluminum.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
CB 1	0	0	0	0	0	0	0	0	11	0
CB 2	0	0	0	0	0	0	0	0	X	X
CB 3	0	0	0	0	0	0	0	0	0	0
CB 4	0	0	0	0	0	0	0	0	<1	0
CB 5	0	0	0	0	0	0	0	0	0	0
CB 6	0	0	0	0	0	0	0	0	X	X
CB 7	0	0	0	0	0	0	0	0	1,100,000*	1,200,000*
CB 8	0	0	0	0	0	0	0	0	10	<1
CB 9	0	0	0	0	0	0	0	0	0	0
CB 10	0	0	0	0	0	0	0	0	X	X
CB 1 - 10 have an "O" ring seal between brass and brass in a rectangular cross sectional groove.										
CB 11	60,000*	64,000*	120,000*	40,000*	7,300*	11,000*	12,000*	16,000*	6,800	6,900
CB 12	27,000*	15,000*	3,000*	3,700*	1,600*	1,200*	1,500*	0*	120	100
CB 13	270,000*	250,000*	110,000*	110,000*	7,800*	11,000*	7,100*	34,000*	X	X
CB 14	34,000*	35,000*	14,000*	22,000*	6,200*	7,900*	7,600*	37,000*	400	400
CB 15	18,000*	16,000*	6,300*	9,000*	2,700*	520*	0*	0*	1	<1
CB 16	0	0	0*	0*	1,100*	0*	0*	0*	0	0
CB 17	40,000*	38,000*	16,000*	24,000*	5,300*	5,800*	10,000*	12,000*	13,000	13,000
CB 18	28,000*	29,000*	14,000*	18,000*	5,100*	4,000*	6,900*	9,400*	0	0
CB 19	28,000*	28,000*	12,000*	16,000*	4,400*	7,500*	2,000*	1,000*	31	34
CB 20	55,000*	55,000*	31,000*	37,000*	8,500*	8,000*	4,300*	13,300*	7,400	7,200
CB 11 - 20 have a gasket seal of cork-neoprene composition (Armstrong DC 100) in a rectangular cross sectioned groove between brass and brass.										
CB 21	0	0	0	0	0	0	0	0	X	X
CB 22	0	0	0	0	0	0	0	0	X	X
CB 23	5,900	5,500	5,800	5,800	210	220	170	160	X	X
CB 24	0	0	0	0	0	0	0	0	X	X
CB 25	0	0	0	0	0	0	0	0	X	X
CB 21 - 25 have an "O" ring seal between brass and brass in a wedge shaped groove.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
CB 26	53,000*	47,000*	52,000*	48,000*	32,000*	30,000*	28,000*	20,000*	120,000*	120,000*
CB 27	32,000*	24,000*	29,000*	24,000*	20,000*	17,000*	220,000*	210,000*	240,000*	220,000*
CB 28	33,000*	33,000*	32,000*	32,000*	21,000*	20,000*	17,000*	14,000*	27,000*	25,000*
CB 29	17,000*	17,000*	17,000*	18,000*	12,000*	10,000*	5,500*	7,600*	32,000*	28,000*
CB 30	17,000*	16,000*	16,000*	17,000*	9,500*	8,600*	1,500*	7,800*	20,000*	18,000*
CB 31	45,000*	37,000*	41,000*	41,000*	25,000*	23,000*	7,000*	17,000*	83,000*	79,000*
CB 32	46,000*	41,000*	42,000*	40,000*	25,000*	23,000*	9,600*	39,000*	57,000*	52,000*
CB 33	39,000*	36,000*	37,000*	36,000*	22,000*	21,000*	9,700*	15,000*	70,000*	68,000*
CB 34	34,000*	34,000*	35,000*	35,000*	23,000*	20,000*	6,900*	16,000*	31,000*	30,000*
CB 35	23,000*	23,000*	22,000*	23,000*	13,000*	12,000*	4,600*	12,000*	16,000*	14,000*
CB 26 - 35 have a gasket seal of asbestos fiber compound in a rectangular cross sectioned groove between brass and brass.										
CB 36	4	<1	<1	0	0	0	0	0	6	<1
CB 37	0	0	0	0	0	0	0	0	0	0
CB 38	0	0	0	0	0	0	0	0	0	0
CB 39	0	0	0	0	0	0	0	0	0	0
CB 40	0	0	0	0	0	0	0	0	0	0
CB 41	0	0	0	0	0	0	0	0	0	0
CB 42	0	0	0	0	0	0	0	0	0	0
CB 43	0	0	0	0	0	0	0	0	<1	0
CB 44	0	0	0	0	0	0	0	0	0	0
CB 45	0	0	0	0	0	0	0	0	0	0
CB 36 - 45 have a gasket seal of natural rubber in a rectangular cross sectioned groove between brass and brass.										
CB 46	64,000*	64,000*	65,000*	68,000*	48,000*	50,000*	50,000*	53,000*	190,000*	250,000*
CB 47	140,000*	130,000*	140,000*	140,000*	120,000*	120,000*	130,000*	130,000*	680,000*	500,000*
CB 48	140,000*	140,000*	140,000*	160,000*	110,000*	110,000*	120,000*	110,000*	26,000*	26,000*
CB 49	77,000*	80,000*	73,000*	86,000*	53,000*	57,000*	56,000*	60,000*	1,900,000*	1,000,000*
CB 50	48,000*	54,000*	49,000*	59,000*	24,000*	26,000*	26,000*	28,000*	8,400*	7,100*

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
CB 51	100,000*	99,000*	97,000*	97,000*	74,000*	72,000*	78,000*	75,000*	47,000*	55,000*
CB 52	85,000*	91,000*	87,000*	93,000*	28,000*	29,000*	30,000*	31,000*	180,000*	240,000*
CB 53	54,000*	67,000*	62,000*	75,000*	50,000*	54,000*	52,000*	61,000*	38,000*	44,000*
CB 54	95,000*	100,000*	100,000*	110,000*	68,000*	66,000*	68,000*	69,000*	31,000*	32,000*
CB 55	110,000*	120,000*	140,000*	120,000*	44,000*	44,000*	43,000*	45,000*	370,000*	230,000*
CB 46 - 55 have a gasket seal of cork-neoprene composition (Armstrong DC 167) in a rectangular cross sectioned groove between brass and brass.										
CS 1	0	0	0	0	0	0	0	0	2,600	2,100
CS 2	<1	0	0	0	0	0	0	0	380,000*	130,000*
CS 3	25	1	5	0	<1	0	0	0	140,000*	42,000*
CS 4	10	0	0	0	<1	0	0	0	26,000	23,000
CS 5	0	0	0	0	<1	0	0	0	38,000*	27,000*
CS 6	1	<1	0	<1	<1	0	0	0	X	X
CS 7	2	0	1	0	0	0	0	0	180,000*	130,000*
CS 8	3	<1	2	0	<1	0	0	0	X	X
CS 9	20	9	17	3	0	0	0	0	X	X
CS 10	0	0	0	0	0	0	0	0	X	X
CS 1 - 10 have an "O" ring seal between steel and steel in a rectangular cross sectional groove.										
CS 11	4,500*	8,800*	5,800*	7,500*	0*	440*	0*	770*	3,200*	3,700*
CS 12	2,300*	2,700*	1,900*	2,500*	4,100*	5,300*	2,200*	4,000*	7,000*	15,000*
CS 13	4,700*	11,000*	5,500*	8,700*	3,500*	5,700*	3,600*	4,700*	19,000*	39,000*
CS 14	4,300*	7,500*	4,200*	6,700*	1,200*	2,500*	1,300*	3,100*	9,500*	10,000*
CS 15	0*	2,100*	0*	2,300*	0*	1,200*	0*	1,600*	1,600*	1,500*
CS 16	2,900*	6,000*	4,100*	6,600*	0*	3,500*	0*	730*	4,100*	9,100*
CS 17	10,000*	20,000*	9,800*	11,000*	49,000*	90,000*	26,700*	86,000*	360,000*	350,000*
CS 18	8,000*	16,000*	7,800*	9,100*	61,000*	64,000*	22,000*	66,000*	270,000*	260,000*
CS 19	29,000*	59,000*	27,000*	38,000*	240,000*	240,000*	240,000*	230,000*	X	X
CS 20	3,100*	4,200*	2,400*	2,900*	3,100*	2,600*	1,200*	1,900*	13,000*	12,000*
CS 11 - 20 have a gasket seal of cork-neoprene composition (Armstrong DC 100) in a rectangular cross sectioned groove between steel and steel.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
CS 21	0	0	0	0	1,200	1,200	330	330	X	X
CS 22	55	46	67	50	<1	0	0	0	X	X
CS 23	<1	<1	<1	0	3,100	3,400	950	1,000	X	X
CS 24	1,300	1,100	1,400	1,400	<1	0	0	0	X	X
CS 25	<1	0	<1	0	<1	0	<1	<1	X	X
CS 21 - 25 have an "O" ring seal between steel and steel in a wedge shaped groove.										
CS 26	5,800	8,700	5,800	5,900	0	0	0	0	0	<1
CS 27	26	20	20	14	0	0	0	0	0	0
CS 28	170	100	110	86	0	0	0	0	0	0
CS 29	11,000	14,000	11,000	11,000	0	0	0	0	0	0
CS 30	11,000	1,300	1,200	1,300	0	0	0	0	0	0
CS 31	36	26	34	27	0	0	0	0	0	0
CS 32	0	0	0	0	0	0	0	0	0	0
CS 33	50	41	43	33	0	0	0	0	0	0
CS 34	1	<1	1	0	0	0	0	0	0	0
CS 35	19	11	19	10	0	0	0	0	0	3
CS 26 - 35 have a gasket seal of natural rubber in a rectangular cross sectional groove between steel and steel.										
CS 36	38,000*	37,000*	40,000*	34,000*	0*	7,900*	5,200*	7,900*	43,000*	43,000*
CS 37	76,000*	72,000*	80,000*	69,000*	0*	19,000*	9,800*	16,000*	96,000*	95,000*
CS 38	66,000*	62,000*	70,000*	60,000*	0*	15,000*	9,400*	15,000*	72,000*	71,000*
CS 39	430,000*	430,000*	500,000*	410,000*	250,000*	250,000*	240,000*	240,000*	330,000*	320,000*
CS 40	79,000*	76,000*	80,000*	73,000*	18,000*	19,000*	22,000*	14,000*	71,000*	73,000*
CS 41	38,000*	37,000*	40,000*	36,000*	6,600*	6,900*	4,100*	7,200*	26,000*	28,000*
CS 42	41,000*	38,000*	42,000*	38,000*	10,000*	11,000*	8,400*	9,400*	31,000*	33,000*
CS 43	31,000*	33,000*	33,000*	30,000*	6,400*	6,300*	4,500*	6,900*	30,000*	30,000*
CS 44	70,000*	68,000*	75,000*	65,000*	24,000*	24,000*	11,000*	20,000*	68,000*	69,000*
CS 45	84,000*	88,000*	93,000*	87,000*	22,000*	23,000*	10,000*	20,000*	61,000*	68,000*
CS 36 - 45 have a gasket seal of asbestos fiber compound in a rectangular cross sectional groove between steel and steel.										

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
CS 46	0	0	0	0	0	0	0	0	<1	<1
CS 47	<1	0	<1	0	0	0	0	0	0	0
CS 48	0	0	0	0	0	0	0	0	0	0
CS 49	<1	0	0	0	0	0	0	0	0	0
CS 50	<1	0	0	0	0	0	0	0	<1	0
CS 51	1	<1	<1	<1	0	0	0	0	0	0
CS 52	0	0	0	0	0	0	0	0	0	0
CS 53	<1	0	0	0	1	3	4	<1	0	0
CS 54	0	0	0	0	0	0	0	0	0	0
CS 55	<1	<1	0	0	0	0	0	0	0	0
CS 46 - 55 have a gasket seal of copper sheet on a 90° ridge between steel and steel.										
CS 56	<1	0	<1	0	0	0	<1	0	15,000	X
CS 57	97	96	180	110	230	260	14,000	64,000*	260,000*	X
CS 58	8	5,500	14,000	12,000	70,000*	9,800*	53,000*	25,000*	400,000*	X
CS 59	3	0	2	0	<1	0	0	0	5,300	X
CS 60	<1	0	<1	0	0	0	0	0	230	230
CS 61	230	720	620	1,300	270	300	250,000*	240,000*	340,000*	X
CS 62	<1	0	0	0	0	4	3	15	120,000*	X
CS 63	0	0	0	0	<1	0	0	0	140,000*	X
CS 64	0	0	0	0	0	0	0	0	170,000*	X
CS 65	4	<1	<1	0	0	0	0	0	73,000*	X
CS 56 - 65 have a gasket seal of lead sheet on a 90° ridge between steel and steel.										
DA 1	4,000*	3,700*	16,000*	31,000*	24,000*	49,000*	54,000*	67,000*	98,000*	73,000*
DA 2	4,700*	5,000*	2,200*	4,800*	1,000	1,000	1,000	1,000	11,000	33,000
DA 3	880*	0*	1,400*	1,900*	0	0	0	0	1,500	1,700
DA 4	1,700*	4,000*	1,500*	3,500*	1,600	1,600	1,800	1,700	1,200	1,200
DA 5	3,600*	4,700*	2,800*	4,900*	8,200	8,700	9,400	9,700	4,400	5,100

TABLE NO. 1 (Cont'd.)

LEAKAGE RATES OF VARIOUS SEALS

Specimen Number	Room Conditions Leakage		After Pressure Leakage		After Humidity Leakage		After Vibration Leakage		After Temperature Leakage	
	In	Out	In	Out	In	Out	In	Out	In	Out
DA 6	2,600*	6,200*	2,500*	5,100*	1,300	1,500	1,700	1,800	2,000	2,200
DA 7	11*	217*	2,000*	300*	3,500	4,700	8,700	9,400	14,000	23,000
DA 8	1,300*	3,100*	3,600*	2,900*	130	94	260	120	650	640
DA 9	2,900*	7,100*	4,100*	5,900*	580	650	660	740	940	1,000
DA 10	4,600*	8,100*	4,400*	6,800*	4,900	4,800	6,600	7,400	2,800	3,100
DA 1 - 10 have seals of lapped aluminum surfaces pressed together.										
DB 1	3,000	3,100	3,100	3,300	2,600	2,600	4,100	4,300	3,300	1,400
DB 2	2,700	2,800	1,200	790	94	89	100	84	2,000	520
DB 3	0	0	0	0	0	4	78	120	990	640
DB 4	<1	1-	4	7	3	2	4	3	1,100	410
DB 5	2,800	3,100	3,100	3,100	2,500	2,400	2,800	2,800	1,800	970
DB 6	21	44	92	134	22	21	47	73	810	560
DB 7	0	0	0	0	0	0	0	0	92	48
DB 8	45	56	83	120	110	100	190	190	750	550
DB 9	1,600	1,700	1,900	1,900	1,300	1,300	1,600	1,800	580	480
DB 10	22	30	58	94	39	35	63	66	920	610
DB 1 - 10 have seals of lapped brass surfaces pressed together.										
DS 1	5,400*	7,300*	5,400*	7,500*	1,400*	6,300*	10,000*	3,600*	1,400*	3,600*
DS 2	5,600*	8,200*	3,300*	8,400*	1,700*	5,200*	7,500*	3,600*	870*	4,600*
DS 3	5,200*	6,800*	3,100*	7,300*	1,300*	3,900*	4,600*	3,000*	160*	3,900*
DS 4	4,300*	6,700*	2,300*	6,300*	5,300*	880*	61*	460*	0*	770*
DS 5	6,300*	12,000*	3,900*	10,000*	250*	620*	0*	0*	0*	0*
DS 6	0*	0*	0*	0*	0*	490*	0*	0*	0*	0*
DS 7	5,900*	8,800*	4,800*	7,200*	600*	4,900*	1,900*	4,200*	2,100*	3,000*
DS 8	4,200*	4,900*	3,000*	3,900*	610*	1,800*	0*	1,200*	1,300*	1,600*
DS 9	6,000*	9,100*	4,200*	8,200*	4,300*	6,300*	12,000*	8,200*	3,500*	5,600*
DS 10	3,900*	3,800*	0*	1,500*	0*	0*	0*	0*	150*	560*
DS 1 - 10 have seals of lapped steel surfaces pressed together.										

TABLE NO. 2

PERFORMANCE RATING OF SPECIMENS
(After specified environmental tests)

Specimen Type	Room Conditions % in Grade				After Pressure % in Grade				After Humidity % in Grade				After Vibration % in Grade				After Temperature % in Grade				Average Rating % in Grade			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
AAA 1-10	100				100				100				100				100				100			
AAB 1-10	100				100				100				100				100				100			
AAB 11-20	100				100				100				100				70	10		20	94	2		4
AAS 1-10	90	10			90	10			90		10		90			10	90			10	90	4	2	4
AAS 11-20	100				100				100				100				100				100			
AAS 21-30	40	40		20	40	40		20	50	30		20	45	35		20	20	50	10	20	39	39	2	20
AAS 31-44		7	14	79		14	7	79		7	29	64		11	21	68		4	7	89		9	16	75
AAS 45-54	100				100				100				100				100				100			
AB 1-10	90		10		90		10		85	15			80	15	5		70	10	20		83	8	9	
AB 11-20	80	10	5	5	95	5			70	15	15		75	15	5	5	50	15	15	20	74	12	8	6
BA 1-10	80			20	80			20	80			20	80			20	70			30	78			22
BA 11-20	60			40	60			40				100				100				100	24			76
BA 21-30	90		5	5	90		10		50	5		45	50			50	50			50	66	1	3	30
BA 31-40	100				100				90	10			100				80	10	10		94	4	2	
BB 1-10	70		5	25	70			30	70			30	70			30	80			20	72		1	27
BB 11-20	70	10		20	60	20		20	30	10		60	30	10		60				100	38	10		52
BB 21-30	100				100				100				100				90			10	98			2
BB 31-40	40	10		50	30	10		60	30	5		65	30	5		65	40			60	34	6		60
BS 1-10				100				100				100				100				100				100
BS 11-20	90	10			90	10			80	10	10		80		20		10	5	5	80	70	7	7	16
BS 21-30		30	10	60		25	20	55				100				100				100		11	6	83
BS 31-40	75	20		5	70	20		10	45	5		50	10			90	5			95	41	9		50
BS 41-50		20	15	65		5	10	85		5	15	80		5		95		10		90		9	8	83
BS 51-60	85	15			80	20			70	30			70	30						100	61	19		20
CA 1-10	100				100				90	10			90	10			90			10	94	4		2
CA 11-15	100				100					20	60	20		30	50	20	20			80	44	10	22	24
CA 16-25	100				100				100				100				100				100			
CA 26-35			20	80			60	40		10	90				95	5				100		2	53	45
CA 36-45				100				100			5	95				100				100			1	99
CA 46-55				100				100			10	90			10	90				100			4	96

TABLE NO. 2 (Cont'd.)

PERFORMANCE RATING OF SPECIMENS

Specimen Type	Room Conditions % in Grade				After Pressure % in Grade				After Humidity % in Grade				After Vibration % in Grade				After Temperature % in Grade				Average Rating % in Grade			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
CB 1-10	100				100				100				100				50	10		40	90	2		8
CB 11-20	10			90		10	20	70		5	85	10		25	40	35	25	15	40	20	7	11	37	45
CB 21-25	80		20		80		20		80		20		80		20					100	64		16	20
CB 26-35				100				100			10	90			45	55				100.			11	89
CB 36-45	95	5			100				100				100				95	5			98	2		
CB 46-55				100				100				100				100			10	90			2	98
CS 1-10	60	40			75	25			100				100						10	90	67	13	2	18
CS 11-20		5	65	30		5	80	15		15	55	30		15	55	30			40	60		8	59	33
CS 21-25	60	20	20		60	20	20		60		40		60		40					100	48	8	24	20
CS 26-35	15	45	25	15	15	50	25	10	100				100				95	5			65	20	10	5
CS 36-45				100				100		15	25	60			50	50				100		3	15	82
CS 46-55	95	5			100				90	10			95	5			100				96	4		
CS 56-65	60	25	15		65	5	20	10	65	5	20	10	60	10		30			15	85	50	9	14	27
DA 1-10		10	90				90	10	10	5	75	10	10		80	10			70	30	4	3	81	12
DB 1-10	25	35	40		20	30	50		15	45	40		10	40	50			10	90		14	32	54	
DS 1-10		10	85	5		15	80	5		15	85			40	50	10		25	75			21	75	4

LEAKAGE RATE

GRADE (IN STD. CC OF AIR/YR/INCH OF SEAL)

Grade	Leakage rate
A	0 - 1*
B	1 - 100*
C	100 - 10,000*
D	10,000 and higher

*The upper limit not included.

TABLE NO. 3

SPECIMEN PERFORMANCE CHART

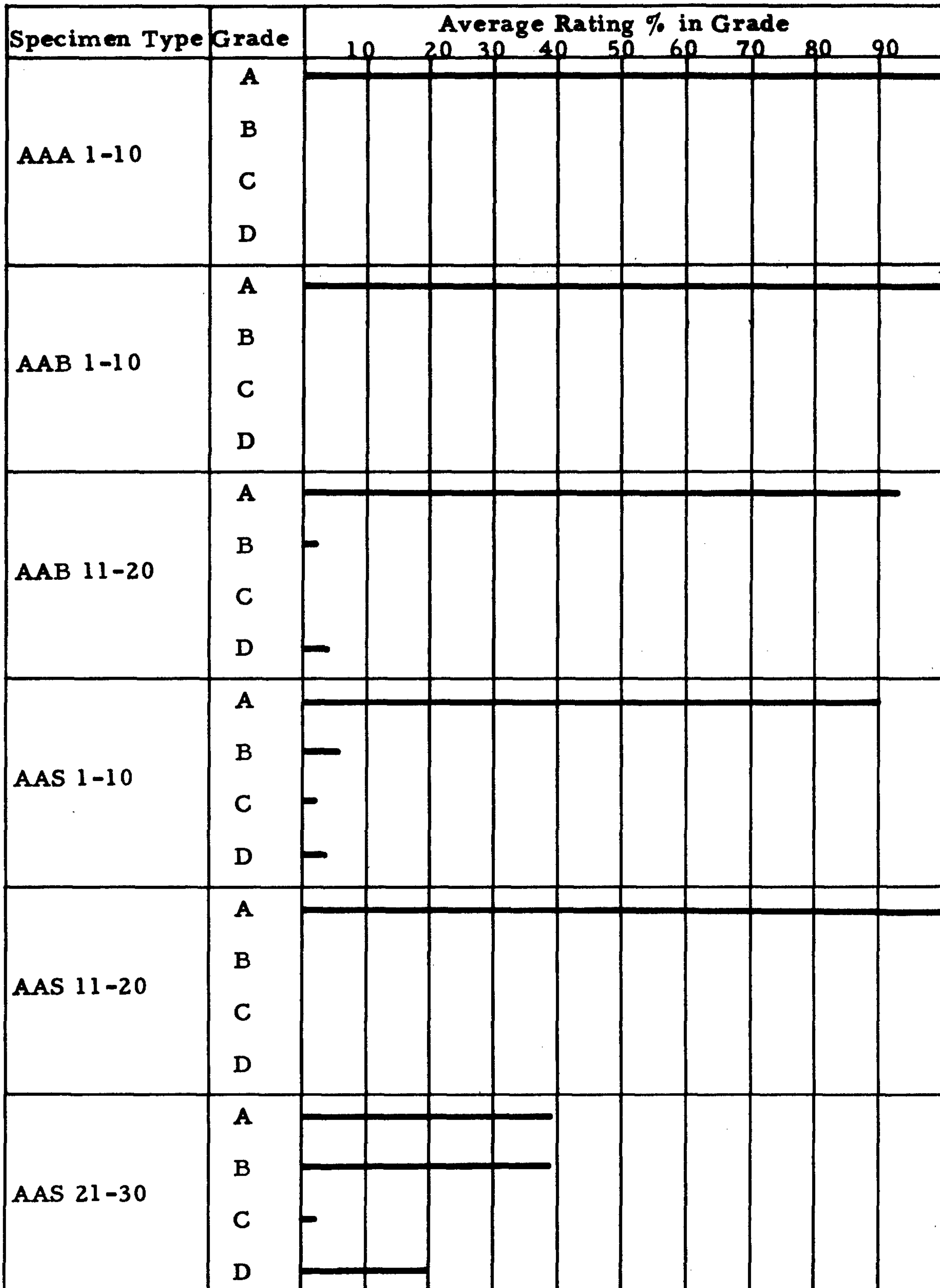


TABLE NO. 3 (Cont'd.)

SPECIMEN PERFORMANCE CHART

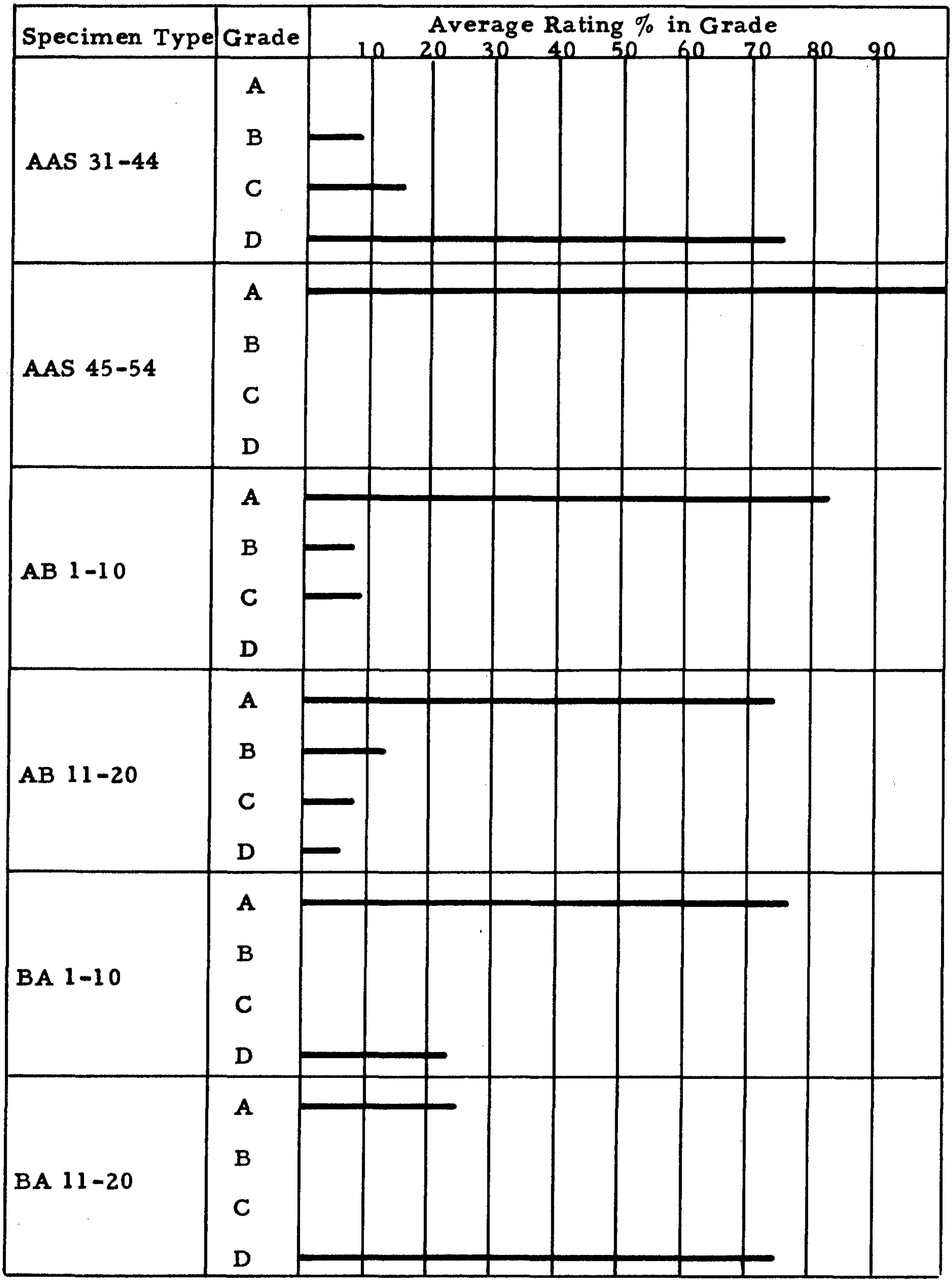


TABLE NO. 3 (Cont'd.)

SPECIMEN PERFORMANCE CHART

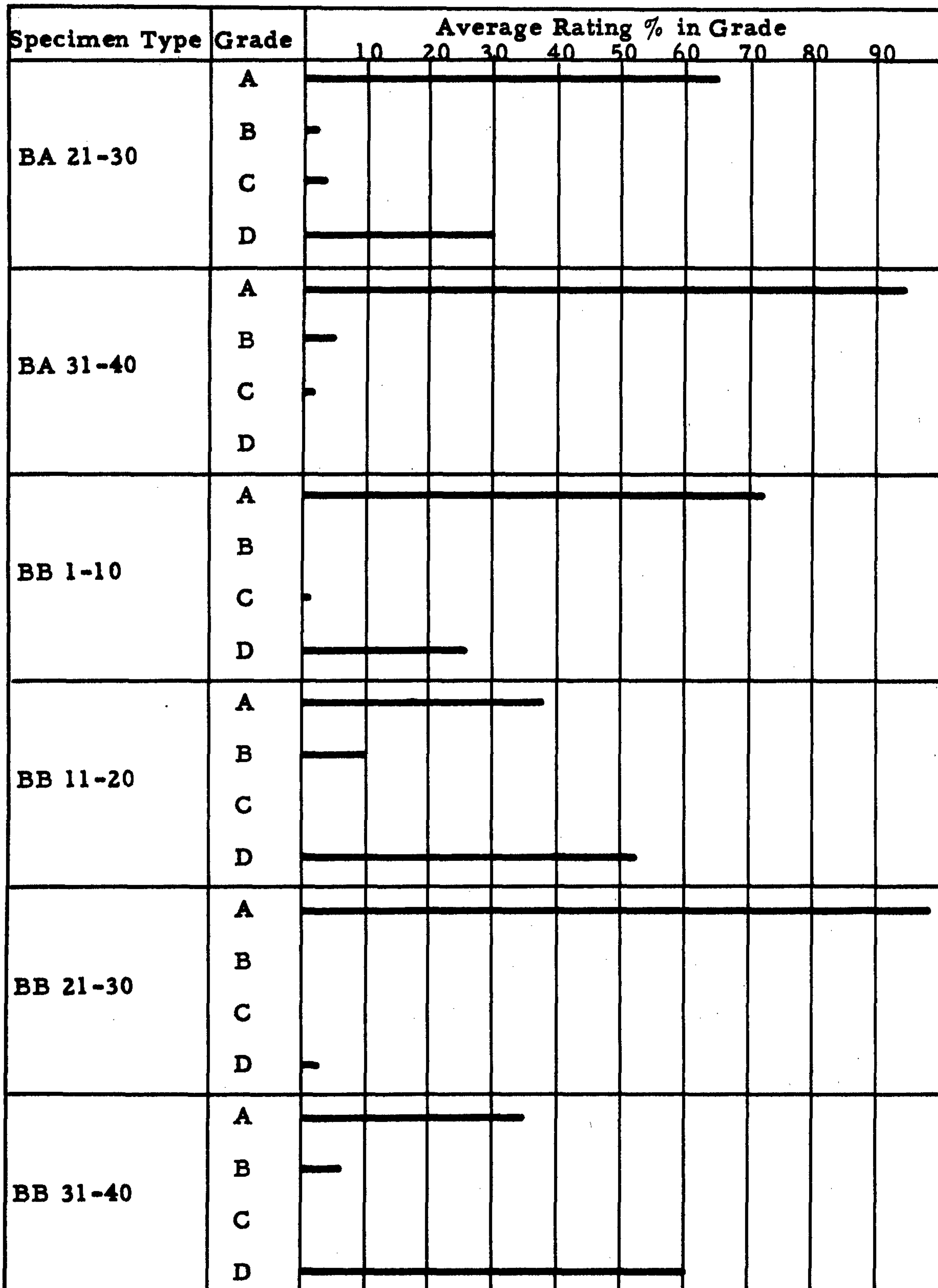


TABLE NO. 3 (Cont'd.)

SPECIMEN PERFORMANCE CHART

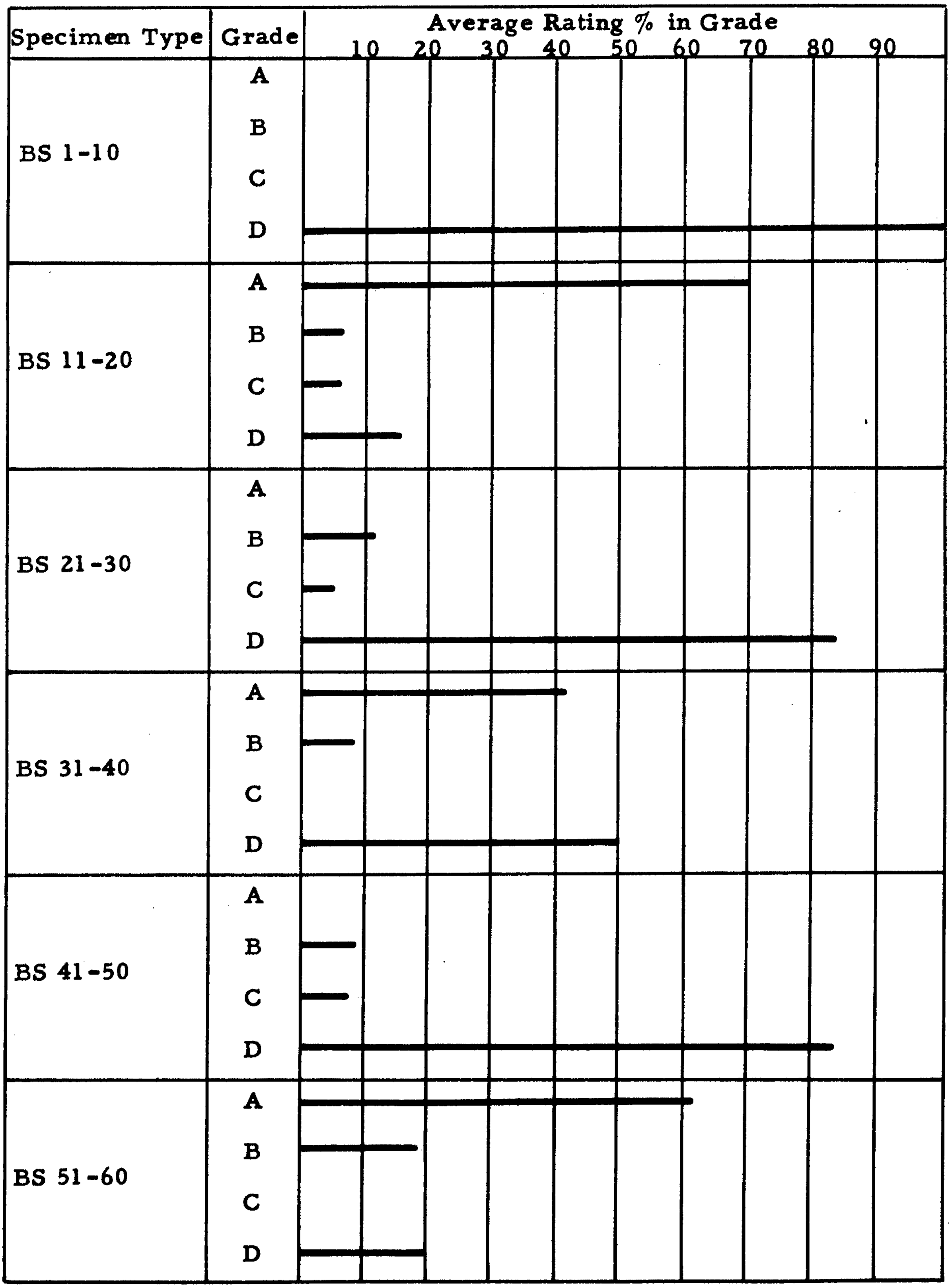


TABLE NO. 3 (Cont'd.)

SPECIMEN PERFORMANCE CHART

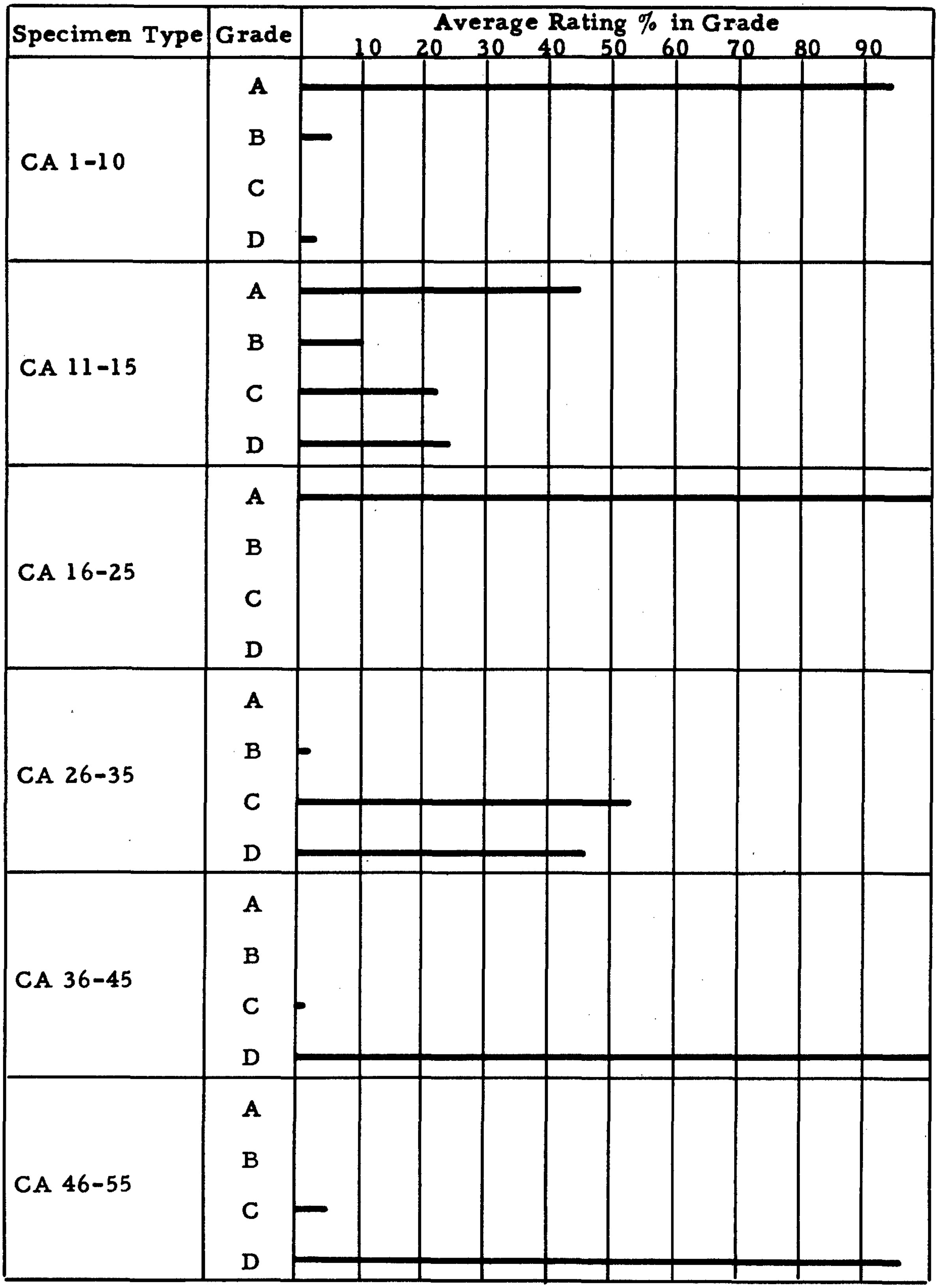


TABLE NO. 3 (Cont'd.)

SPECIMEN PERFORMANCE CHART

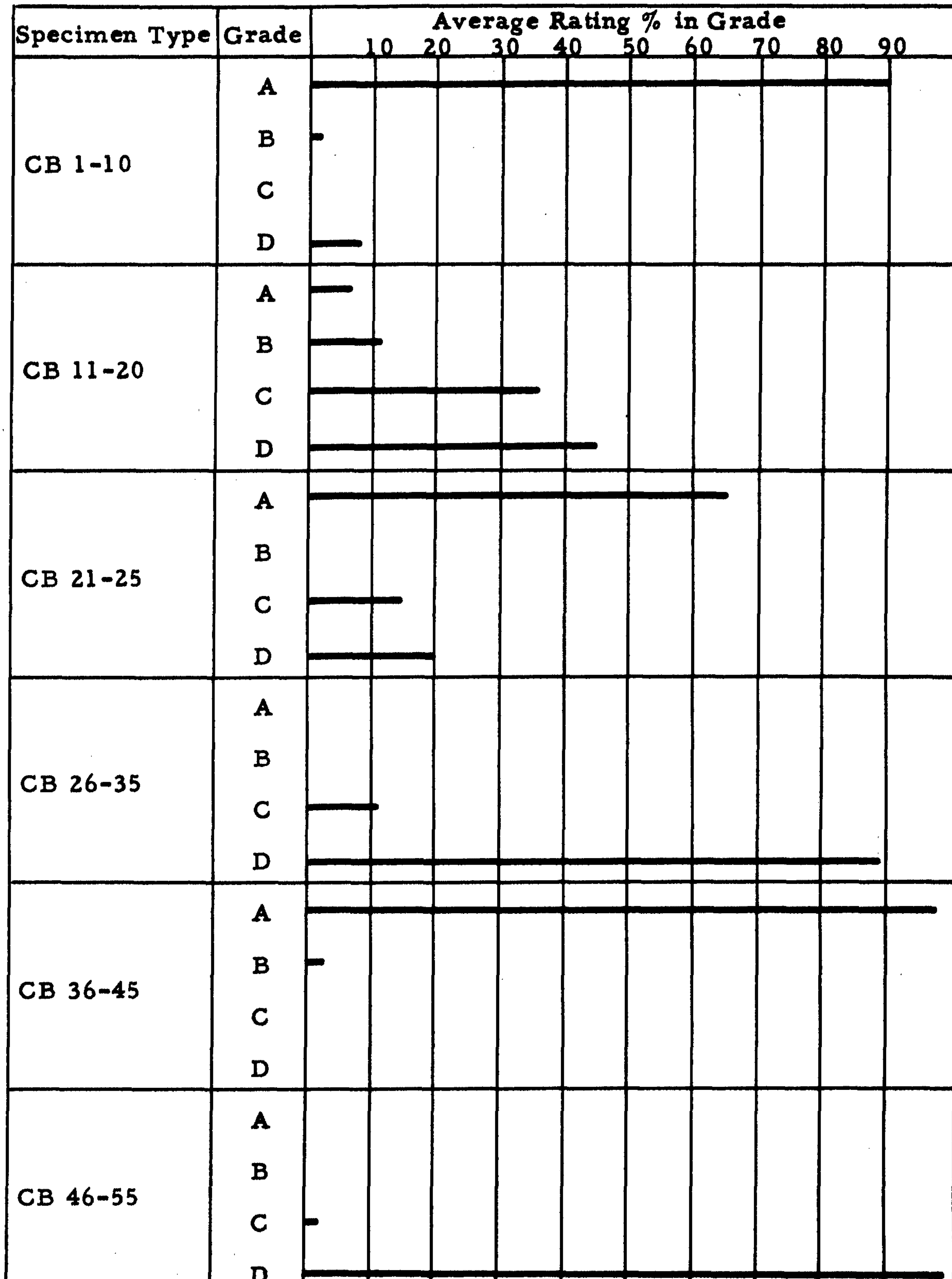


TABLE NO. 3 (Cont'd.)

SPECIMEN PERFORMANCE CHART

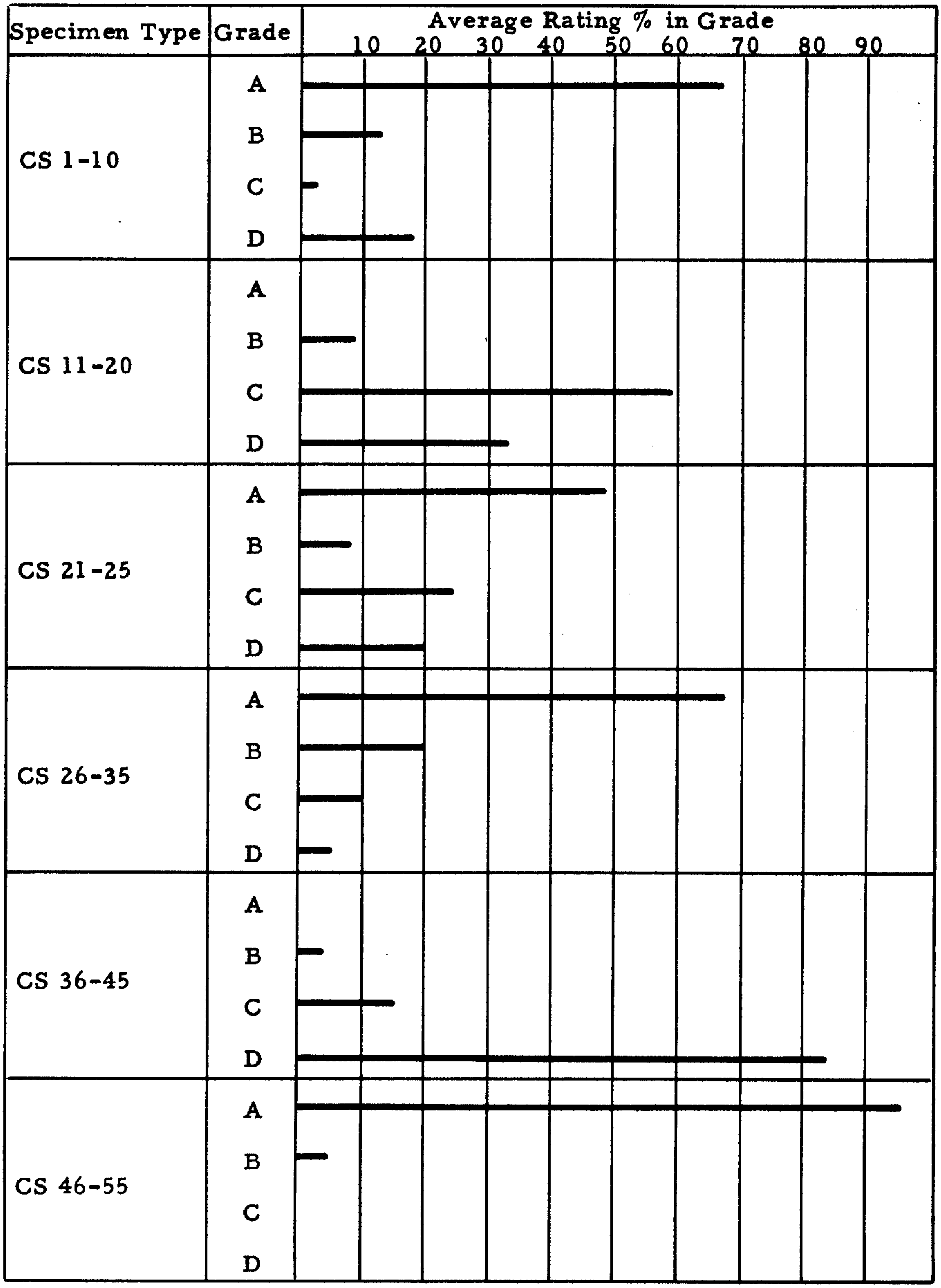


TABLE NO. 3 (Cont'd.)

SPECIMEN PERFORMANCE CHART

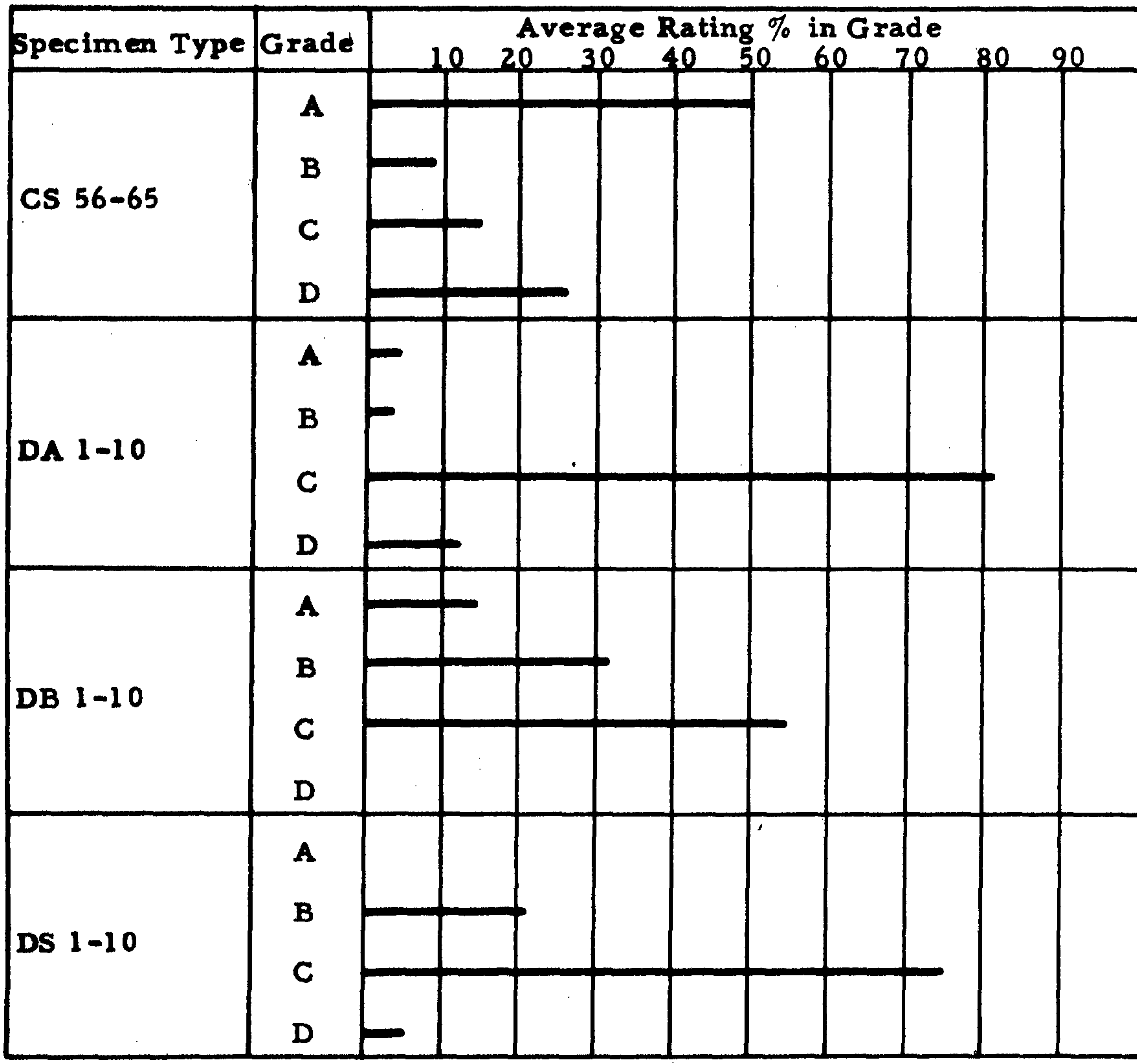


TABLE NO. 4

TRADE NAMES AND SUPPLIERS

The following list of products and their source of supply is included as a convenience for ordering some of the less familiar items used on this project:

Welch vacuum pumps	W. M. Welch Manufacturing Co.
Hoke vacuum valves	Hoke Incorporated
Flexible metal bellows	The Fulton Sylphon Company Clifford Manufacturing Co.
Trubore capillary tubing	Ace Glass Incorporated
Dri-film 9987	General Electric Co.
"O" rings	Linear Incorporated
RCA-1945 hydrogen ion gauge	Radio Corporation of America
Vacuum stopcock grease	Dow Corning Corporation
Glass to metal seals	Electrified Industries, Inc. The Fusite Corporation Stupakoff Ceramic & Mfg. Co.
Nichrome wire	Driver-Harris Co.
Thermocouple gauge	National Research Corp.
Kinney vacuum valves	Kinney Manufacturing Co.
Vacuum rubber turing	Central Scientific Company
Opal glass panel	Eastman Kodak Co.
Calibrated leaks	General Electric Co. Vacuum-Electronic Engineering Co.
EutecRod 190 & Eutector Flux #190	Eutectic Welding Alloys Corp.
Anti-Borax No. 16 flux	Anti-Borax Compound Co., Inc.
Rubyfluid soldering flux	The Ruby Chemical Co.
Nitro-Seal	The Varniton Co.
Selectron 5208	Pittsburgh Plate Glass Co.
Silastic 120	Dow Corning Corporation
Araldite, type XI	Ciba Company, Inc.
Neo-Sil	Neo-Sil Corporation

DISTRIBUTION LIST

Copies	Activities at Wright-Patterson Air Force Base
5	DSC-SA
1	WCOSI (RAND)
1	WCOSI (for Office of Technical Services, Dept. of Commerce)
3	WCOSI-4
48	WCREO-2
1	WCLMR Attn: R. J. Framme
1	WCLRE Attn: C. N. Keller
2	WCLGO Attn: Maj. T.F. Warns Attn: R.H. Nordlund
1	WCLNE Attn: E.R. McCappin
1	WCLNO Attn: L. Hendricks
1	WCLN Attn: L.B. Hallman
1	WCLE
1	WCRTO-5
3	WCOSR (for possible foreign release)
1	WCLFA-3

Copies	Other Department of Defense Agencies
	Air Force
3	Commander Air Force Cambridge Research Center Attn: Documents Unit, CRQST-2 230 Albany Street Cambridge 39, Massachusetts
1	Commander Rome Air Development Center Attn: RCRES-4C Rome, New York
1	Commander AF Missile Test Center Patrick Air Force Base Cocoa, Florida
1	Director Air University Library Maxwell Air Force Base, Alabama
1	Chief Technical Library Office of Asst. Secretary of Defense (R&D) Room 3E 1065, The Pentagon Washington 25, D. C.
1	AF Development Field Representative Attn: Code 1010 Naval Research Laboratory Washington 25, D. C.
1	AF Development Field Representative Armed Services Electro Standards Agency Attn: Mr. Clayton J. Held Fort Monmouth, New Jersey
1	Chief European Office Air Research & Development Command Shell Building 60 Rue Ravenstein Brussels, Belgium
	Army
1	Commanding General Redstone Arsenal Attn: Technical Library-EC Huntsville, Alabama
1	Commanding General Signal Corps Engineering Labs. Attn: Technical Documents Center Evans Signal Lab Area, Bldg. 27 Belmar, New Jersey
1	Commanding General Joint Tactical Support Board Dept. of Equipment Fort Bragg, North Carolina
	Navy
1	Chief Bureau of Aeronautics Electronics Division Material Coordination Unit Department of the Navy Washington 25, D. C.

Copies	Other Department of Defense Agencies
	Navy
1	Chief Bureau of Aeronautics Attn: Technical Data Division TD-414 Navy Department Washington 25, D. C.
1	Chief Bureau of Ships Code 816 Navy Department Washington 25, D. C.
1	U.S. Navy Electronics Laboratory Attn: Mr. A. H. Attebury Code 733 San Diego 52, California
	Miscellaneous
2	National Bureau of Standards Division 12 Attn: Mr. Ben Davis Division 12.1 Attn: Mr. Gustave Shapiro Washington 25, D. C.
1	National Security Agency 4000 Arlington Boulevard NSA-36 Washington 25, D. C.
10	Bjorksten Research Laboratories Attn: Mr. Robert J. Roth 323 West Gorham Street Madison 3, Wisconsin